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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Engines for Small Propeller-Driven RPVs

Volume I

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Report of Sub-Group A of AGARD Working Group

on

Propulsion and Power Supplies for Unmanned Vehicles.

VOLUME I.

This Advisory Report was prepared for the Propulsion and
Energetics Panel of AGARD

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

Propulsion and Energetics Panel

Working Group 06

Propulsion and Power Supplies of Unmanned Vehicles

GENERAL INTRODUCTION

The Propulsion and Euergetics Panel of AGARD has founded a Working Group for the study of the propulsion and power supplies of unmanned vehicles, which started his activities in 1975.

This Working Group (WG 06) studied in separate sub-groups the propulsion of three types of unmanned vehicles:
- small-propeller-driven Remotely Piloted Vehicles (subgroup A)
- small turbojet-driven Remotely Piloted Vehicles (subgroup B)
- false targets (sub-group C).

Originally also the study of the propulsion of anti-ship missiles was planned (subgroup D), which after some initial investigations, was deleted to avoid the duplication of other work already started within the NATO-community.

A summary of the work of all groups will be published in a seperate executive report by the chairmen of the subgroups.

In this volume the study performed by subgroup A is presented and this introduction offers a good opportunity to thank the members of the sub-group for their efforts devoted to this study, which may be rewarded by the interest shown by the readers.

It is hoped that the results of the studies undertaken in the Working Group may foster further research and development on unmanned vehicles to the benefit of the NATO-countries.

Prof. H. Wittenberg,
Chairman Working Group 06 of the
Propulsion and Energetics Panel.

1. INTRODUCTION

The consideration of small propeller-driven Remotely Piloted Vehicles (often called Mini-RPV's) in the field of military operations is demanding the attention of the aeronautical community for small piston engines again. The modern piston engine is well developed for application in all types of small and medium-sized manned aircraft for civil and military use, but because of the much lower total weight of the vehicle, the small RPV's require engines of considerably less horse power.
This is illustrated by the data in Table 1.1, which gives the main characteristics and performances of some American RPV-types. A fairly large number of these small piston engines are available on the market, their design being aimed at a wide scale of applications, mostly in the non-aeronautical field.
Besides the four-stroke cycle piston engine, mostly used for manned-aircraft, the two-stroke cycle engine is very suitable for application to many small RPV's, but other shaft-power engine types might also offer certain advantages.
The aim of this study follows from the terms of reference, which were defined by Working Group 06 for sub-group A:

a. To prepare a short survey of the state of the art of the propulsion technology of small, propeller-driven Remotely Piloted Vehicles as used for several missions, e.g. battle field surveillance, target-designation and defense suppression.
b. To give an outline of the efforts which are required to improve the engines for application into operational RPV's.
c. To prepare an inventory of available engines and their main characteristics (power, weight, fuel consumption, etc.).

The members of the working group on this study are listed in Appendix 1, which gives also the dates and locations of the five working-meetings of the group. Most of the actual work has been performed by the members on an individual base; the meeting-sessions were aimed at discussions on the lay-out of the study, on the separate contributions of the members and on editorial work for the final report.
The results of the study are presented in the following sections. Section 2 summarizes the inventory of existing engines. As part of this inventory Weslake & Company Ltd., Sussex, England, were contracted by AGARD for data collection on existing engine types. Their efforts lead to an extensive set of data, which was considered as a very useful survey and has been added as Appendix 2 to this report. These data are preliminary to the choice of an engine by the vehicle designer. Following choice of engine, more extensive engine data are to be derived from an engine model specification, as illustrated by some examples. Besides the normal two- and four-stroke cycle piston engines, section 2 deals also with other shaft-power engine types to investigate their suitability for application to RPV's.
In Section 3 the requirements for small RPV's are considered in relation to several mission requirement, which have been based on the best knowledge available to the members of the sub-group to investigate the relationship between the RPV-vehicle and the engine characteristics, some simple parametric calculations are also presented in this section.
In section 4 the engine requirements are considered in more detail and compared with existing engines. Also a typical generalized specification for unmanned aircraft engines is presented.
The final sections 5 and 6 give the conclusions and some recommendations, which follow from this study.

The reader will not find in this report the use of an unified system of units for the vehicle and engine characteristics; all data are presented as given by the originator. To unify all data to the SI-system would have been a large effort, considered not worthwile in view of the use of the data in practice.
For the readers' convenience the most important conversion factors for this report are given below:

multiply	by	to obtain
feet (ft)	0.3048	meter (m)
pound (lb)	0.4536	kilogram (kg or kp)
horse power (hp)	0.7457	kilowatt
"	550	ft.lb/sec
"	1.0139	metric horsepower (pk)

2. INVENTORY OF EXISTING ENGINES

2.1 General.

Study of missions defined within the context of AGARD sub-group A, and also within the context of a specific U.K. requirement for a rotary-wing surveillance RPV, revealed both a lack of suitable low-horsepower engines and a lack of reference data on engines which are available. Mission data were used to derive a broad spectrum of engine power requirements, as a first approximation and this spectrum of useable power was used to define a comprehensive survey of piston engines and other engine types.
The maximum power of interest was quickly established up to 100 hp, based on representative values of endurance, speed and payload. However, the preponderance of required power lay in the region of 10-50 hp and this quickly revealed the greater availability of two-stroke and four-stroke piston engines than gas-turbines or other types, such as rotary-piston, Diesel, Stirling or electric. Accordingly, the inventory presented in this Section is mainly devoted to the first engine category and very limited reference is made to other engines. This in no way infers a desirable situation. Rather it underlines the status in which designers of RPV-vehicles are forced to choose, usually two-stroke piston engines, or sometimes four-stroke, because other types, which may be more desirable in certain respects such as vibration or noise, are not available in the numbers required for a

generalized engine search. Further, it allows us to define areas of engine R & D, reflecting the inadequacies in the currently available two- and four-stroke piston engines, in the direction of other engine types.

2.2. Generalized power requirements

2.2.1. Generalized power requirements can be derived from the simple identities for vehicle weights:

$$W_s + W_E + W_F + W_P = W_{TO} \qquad (2.1)$$

where:

W_S = structural weight

W_E = engine weight

W_F = fuel weight

W_P = payload weight (including equipment)

W_{TO} = all-up weight (take-off weight)

The weight equation can be rewritten with the engine brake-horse power P_{br}:

$$\frac{W_S}{W_{TO}} + \frac{W_E + W_F}{P_{br}} \cdot \frac{P_{br}}{W_{TO}} + \frac{W_P}{P_{br}} \cdot \frac{P_{br}}{W_{TO}} = 1$$

or

$$\frac{W_E + W_F}{P_{br}} = \frac{W_{TO}}{P_{br}} \left[1 - \frac{W_S}{W_{TO}} \right] - \frac{W_P}{P_{br}} \qquad (2.2)$$

This expression indicates the maximum allowable values of propulsion specific weight $(\frac{W_E + W_F}{P_{br}})$, which can be assigned to a vehicle for given power loading $(\frac{W_{TO}}{P_{br}})$, payload W_P (including equipment), horsepower P_{br}, and representative structural weight fraction $(\frac{W_S}{W_{TO}})$.

For the range of vehicles considered, values of these parameters have been chosen on the basis of representative vehicles and payloads. These assumptions are summarized as follows:

1. W_{TO}/P_{br} = 4.0, 5.0, 6.0 8.0, 10.0 lb/hp
2. W_P = 20 - 60 lb
3. P_{br} = 10 - 100 hp
4. $\frac{W_S}{W_{TO}}$ = 0.30

With this fixed value of W_S/W_{TO} (=0.30), the identity for propulsion specific weight becomes:

$$\frac{W_E + W_F}{P_{br}} = 0.7 \frac{W_{TO}}{P_{br}} - \frac{W_P}{P_{br}}.$$

Hence for the range of values of power-loading, payload and horsepower, indicated above, corresponding values of maximum allowable specific propulsion weight can be deduced. It is to be noted that the range of values considered here, is indicated as the useable range from numerous design studies of vehicles, both fixed-and rotary-wing, based on representative payloads and mission durations. For example, different sensor payloads including cameras, IR- and/or TV-units with particular dimensions and masses, leading to unique vehicle geometries and sizes, will fit into the considered range of parameters when allowance is made for fuel requirements to mission durations of between 0.5 - 2.0 hours.

The derived values of $\frac{W_E + W_F}{P_{br}}$ are presented graphically in Fig. 2.1 - 2.3 for payloads of 20, 40 and 60 lb. These values of propulsion specific weight are shown as upper boundaries for each value of power loading W_{TO}/P_{br} between 4 and 10.

2.2.2. Generalized propulsion specific weights from available engines are shown in Fig. 2.4. Here, curves for the specific engine and fuel weight $(\frac{W_E + W_F}{P_{br}})$ are presented as a function of BHP for mission times of zero, 1 hour and 2 hours, operating at rated power and corresponding SFC. For the 2-stroke in 4-stroke piston engines, the curves are derived from the Weslake survey (Appendix 2), taking the lower boundary from all engine data for each mission time[x]. Moreover, in Fig. 2.4 the specific

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[x] The curves for 0,1 and 2 hr mission time are not equidistant for the piston engines, because for a given BHP the points on the curves will correspond to different engine types.

propulsion weight is given for the Lucas turboshaft derivative, CT 2047, which discussed in section 2.4.1.
The curves in Fig. 2.4 indicate the propulsion specific weights which are assignable to any vehicle for a chosen BHP and mission flight time, and indicate the relative advantages of 2-, 4-stroke and turboshaft engines over the power range 10-100 BHP.

2.2.3. In order to allow a comparison between the two sets of data on maximum allowable and actual assignable propulsion specific weights, the representative engine data derived from the Weslake survey of current engines (plotted in Fig. 2.4) are overlaid on the data shown in Fig. 2.1 - 2.3 for mission times of 1 and 2 hours.
As an example, suppose that considerations of wing- or disc-loading have led to the co lusion that a power loading of 8.0 is appropriate to a vehicle required to carry a payload of 60 lb on a 2-hour duration mission. Then from Fig. 2.3 it is indicated that a minimum vehicle power of about 31 BHP is required (point A). Smaller vehicles will not have engines available to them with a low enough value of propulsion specific weight to carry out the 2-hour mission with that payload.
Thus, if an engine of only 24 BHP were available, instead of 31 BHP, than this size engine, with its appropriate specific weight is better sized to a vehicle of 2-hour duration, but with a 40 lb payload (Fig. 2.2, point B), or if the 60 lb payload were mandatory, than Fig. 2.3 indicates that the same vehicle would have only 1-hour mission duration (point C).
Alternatively, if for the payload of 60 lb choices of power loading between 4.0 and 10.0 were options to the air-vehicle, from such considerations as manoeuvrability or hovering, then Fig. 2.3 indicates that vehicle minimum power requirements range from close to 100 BHP for a power loading of about 4.0 to about 20 BHP for a power loading of 10.0, given the propulsion specific weights of current engines.

2.3 Conventional piston engines

2.3.1. The inventory of piston engines in the power range of 10 and 100 BHP, currently available, is given in Appendix 2. The data in this appendix are in the format as used by the Weslake & Company Ltd, who conducted the engine survey on request of AGARD.
This inventory does not only illustrate the overall piston engine availability in the relevant power range, but allows also the selection of engine(s) for particular project(s). Choice of an engine may be made from such a survey using parametric power requirements, as a first approximation, but more specific details of any engine are required for design and installation purposes. This type of engine information is contained in engine model specifications and two examples are shown in Appendix 3. A typical engine at the lower end of the power range is the McCulloch 101D (12 hp/two-stroke) and the attached engine data sheet illustrates the type of sparse documentation available for such engines, which of course, were not designed for RPV's, but for Go-Carts. By contrast the specification of the larger engine, Rolls Royce Continental-200-A, conforms more generally to that required in normal aircraft-propulsion practice, but it is an engine which is too large for the majority of RPV applications.

2.3.2. In Appendix 4 an example of a specification written by the Department of the Army in the U.S.A. especially for RPV engines is given, which illustrate the trend towards more formal documentation supporting the requirements for small RPV engines. This particular RPV engine specification has recently been used for an official request for quotations for a 20 BHP two-stroke engine to be used as a demonstration RPV engine. It's detailed contents are worthy of note and it is the typical format for U.S. RPV engines (see also section 4).

2.3.3. Further analysis and detailed presentation of the Weslake inventory data is shown in Fig. 2.5 - 2.8 which show engine parameters, such as specific weight, specific fuel consumption and overall efficiency as a function of take-off power for two-stroke glo(w)-fuel, and two-stroke and four-stroke engines using conventional petrol/oil and petrol fuels for land vehicles. Also in Fig. 2.9 the mean piston speed (metres/second) versus engine shaft speed is indicated, which is a useful parameter for engine choice on the basis of engine-wear potential.

2.4 Other engine types

Other engine types are less amenable to the broad parametric and detailed design considerations possible for conventional piston engines, due to their relative non-availability for RPV applications. Such engines include the following types:
2.4.1. Turboshaft engines
2.4.2. Rotary-piston engines
2.4.3. Stirling-cycle engines; other cycles
2.4.4. Electric propulsion systems

The current status of these engines and their judged place in the RPV-engine spectrum is summarized below under these paragraph headings.

2.4.1. Turboshaft engines

In comparison with the conventional piston engines the turbo-shaft engine can potentially offer several advantages for application to RPV's, such as:

- low vibration
- low noise
- high reliability and low level of maintenance
- good flexibility on fuel types
- compact system

Some disadvantages of the turbo-shaft types are the requirement of a light-weight, high-ratio reduction gear and in general the high development and unit-production costs of gasturbines.
The turbo-shaft engine is widely used in aircraft practice, in particular in helicopter applications, but is generally available only at power levels considerably higher than that envisaged for RPV application. Consequently the development of turboshaft power systems for RPV's has been studied in terms of derivations of low power (< 100 hp) units from existing A.P.U.'s, which exist in fairly

large numbers at the lower power levels, although still scarce at the level defined in 30-50 hp bracket, with none at all identified below this. The general position is well described in a statement covering an inventory survey of existing turboshaft engines by the U.S. observer member of subgroup A. This is attached as Appendix 5 together with an inventory of suitable APU's amenable to appropriation of the power turbine assembly for development into RPV turboshaft engines. The original intention of the inventory could not be met as no suitable turboshaft engines, in propulsion form, could be identified.

An attempt at filling a typical 30-50 HP requirement by means of a turbo-shaft engine derived from an available APU has been made in various design studies. One typical example of such a study is reported in Appendix 6, which presents the performance, specific weights and specific fuel consumption of a single-shaft turbine engine, designated Lucas CT 2047 and derived from the Lucas CT 2009 APU. As far as is known, an engine of this type and power does not exist and the design study reported in this appendix seems to typify the status of turboshaft engines for RPV at the moment.

From Fig. 2.4 can be seen that the specific propulsion weight of this turbo-shaft engine will be competitive with available piston engines for flight durations up to about 1 hour.

2.4.2. Rotary-piston engines

In general, rotary piston engines may offer advantages for the application of RPV's due to their favourable power/weight ratio and the small residual unbalance.

Mass production experience and availability of rotary piston engines -type WANKEL- refer basically to the automobile industry. There is only little experience with small size units (Fichtel and Sachs KKM 27/Outboard Marine), and the production volume is gradually decreasing. The following main trouble sources have been identified:

- high fuel consumption ($\geq$.350 kg/hp-h)
- insufficient combustion
- insufficient reliability
- high production costs

A typical example of an alternative solution is offered by the Dornier-Huf system (Fig. 2.10), which implements basic advantages of the rotary piston technique, such as

- capability to get mathematically precisely balanced
- lower weight
- small size
- realization of high rpm's

Significant compensating advantages with regard to the trouble sources are in principal

- the apex seals are mounted in the housing and therefore free of centrifugal forces
- the combustion chamber is located in the housing offering complete freedom of design
- the system being a positive displacement system enables high compression ratio's

The Dornier-Huf system is still in a very early stage of development. Some laboratory models of an air compressor and a two-stroke engine are built and tested. Further research and development will be required to investigate the potential of this engine for RPV-applications.

2.4.3. Stirling- and other cycle engines

Unlike the situation for the previously considered engines, i.e. turboshaft and rotary-piston, where a limited number of actual engines, or at least the established technology of derivable engines is available, this does not apply to the Stirling engine. This engine type does not exist in the context of an established technology. Therefore this section will present the reasons for their potential use, the estimated values of particular engine parameters resulting from the limited research work in progress today. and judge their usefulness to RPV propulsion on the basis of these available data.

The potential advantages cited for this engine are as follows:

- high efficiency at partial load
- low noise and vibration
- low exhaust emission characteristics
- no oil changes during service life
- reliable starting, long service life
- external heat source, multi-fuel capability

In an assessment of this engine for aircraft application NASA has indicated a weight/power ratio of 5 lb/hp for current engines of about 100-200 hp[x)]. NASA has made a request for proposals aimed at demonstrating an engine design of not more than 200 hp, with a specific weight of 1.65 lb/hp or less. These studies are asking for an experimental engine, which might be built within five years and would lend itself to series production at costs competitive with other aircraft engines for the same application within ten years.

The complication, both in weight, cost and complexity (and vulnerability) of the Stirling engine lies in the heat-exchanger/external heat source/working fluid transfer system. The effect of working fluid and working pressure on engine specific weight is illustrated in Fig. 2.11. This indicates the high specific weights envisaged and shows that the lowest values of this important parameter can only be reached at high working pressure, with hydrogen as the working fluid and at power levels above about

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x) This figure holds e.g. for the Philips 4-215 DA Stirling motor (170 hp, double acting swash-plate type) for car application, with all auxiliary equipment included (bare engine about 3 lb/hp).

100 hp. At the low powers of interest to RPV's, i.e. 10-50 hp the specific weights envisaged are several times that of the currently available piston engines.
If a judgement has to be made, on the basis of both availability and the prospects of improvement over current piston engines, it seems that the Stirling engine has to be ruled out as a candidate for low power RPV-application other than in the long term future. Moreover, the prospects for a high-performance Stirling engine with simple air cooling and no secondary fluid loop seems to be virtually zero.

Other cycles might include the Diesel, but a survey of engines shows that the specific weight of small Diesel engines is much too high for further consideration for RPV application.
For RPV-rotorcraft a particular engine/rotor combination might be the tipmounted ramjet or pressure-jet. The subsonic ramjet has a very high specific fuel consumption; in this respect the pressure jet seems more promising, but this concept is in a very early stage of research and development only.

2.4.4. Electric propulsion systems

No inventory of electric engines can be compiled at this time because the concept of electric propulsion is still in the feasibility stage of evaluation. However, the characteristics of a variety of battery types that could provide the required power to satisfy a Mini-RPV weighing between 30-50 pounds can be given. The cruise power of this vehicle would require between 1-1½ HP (745-1120 Watts) with level loiter power of about one-half this level. The characteristics of a variety of batteries that could satisfy these power requirements for an anticipated one-hour mission are presented in Table 2.1. The more conventional types (Nickel-Zinc, Nickel-Cadmium and Lead-Acid) and the thermal types of batteries are obviously much too heavy to be considered for the described mission. Only the lithium (Li-SO_2, Li-$SOCl_2$, etc.) and silver-zinc "primary" type batteries would be attractive from a weight standpoint. However, the use of primary (non-rechargeable throw-away) type batteries could present a problem of maintenance and supply since these batteries would require replacement after each mission. In a multi-mission application, cost could also become a factor. Allowing for weight increases for a larger type vehicle would permit the consideration of the somewhat heavier secondary (rechargeable) type batteries.

With regard to storage life, the only batteries that would have shelf lives of up to 10 years would be the thermal cells and the reserve-activated type systems which could be kept in a dry state until activated. The newer molten salt systems and solid electrolyte are still in the development stages and are currently plagued with problems. Also from an operational standpoint, battery energy densities somewhat less than the indicated levels may be expected during the latter parts of a mission, particularly if high discharge rates are required early in the mission.

The many advantages of electric propulsion, such as instant start and on-off flight control, certainly warrant its consideration for Mini-RPV application and continued development of high-energy density batteries. Accordingly in the U.S., the Advanced Research Projects Agency (ARPA) has contracted to companies such as Northrop to explore the potential of battery-powered vehicles in the weight range of approximately 30-50 pounds.

2.5 Conclusions on existing engines

2.5.1. State-of-the-art piston engines and design-study turboshaft engines in the power range 10-100 hp and 30-50 hp, respectively, have been compared graphically in Fig. 2.4, on the basis of propulsion specific power for zero, one hour and two hours flight time. When matched to the power required for vehicles with payloads in the range of 20 to 60 lb (Figs.2.1-2.3), it shows that most power requirements can be satisfied with the piston engines available and with the design-study turbo-shaft engines.
Therefore a basis exists for a reasonable wide range of piston-engined RPV's, and it seems feasible to base vehicle designs on turboshaft engines with current technology available (at least up to 1 hour flight time).

2.5.2. In general, the group of piston engines within the power range of 10-20 hp gives a wrong impression on a weight basis, if only their low specific engine weight is taken into account (Fig. 2.6). When examined for 1 or 2 hours flight time, their propulsion specific weight (engine + fuel) increase dramatically, due to their high fuel consumption, usually as a result of methanol-fuel usage (Fig. 2.4). Some of these engines were designed for RPV's, but do not exhibit a great improvement over the engines used for Go-Carts, Chainsaws, Snow mobiles, etc.

2.5.3. Although not examined systematically due to lack of data, the glow-fuel engine types, when considered for RPV-application, are known to have short lives and need conversion to petrol fuels, when used operationally. They generally exhibit questionable engineering integrity and are (usually) very expensive.

2.5.4. Again, although not systematically analyzed, the commercially available conventional-fuel engines for Go-Carts, Snow-mobiles etc., application, need considerable modification, particularly in areas such as cooling fans (systems), combustion, alternator/ignition design and exhaust system tuning. Often single cylinders need to be coupled either through a gearbox or a new crankshaft in order to produce particular power levels. These engines, at powers above about 20 BHP are generally more robust than the lower power, glow-fuel types below 20 BHP, but they also suffer from many disadvantages. Again, in general terms, one can state that for instance the McCulloch 101B engine (for Go-Carts), which has been used in the AQUILA programme, has the fewest undesirable features, rather than being the most desirable engine.

2.5.5. Drawing on generalized experience of these piston engines, in the range up to 50 hp it can be stated that the following undesirable features are characteristic of engines, acceptable for RPV's on the basis of power available:

- Marginally acceptable, but high specific weight
- High vibration, requiring special mounts
- High noise level
- Possible cooling problems
- Uncertain reliability
- Poor quality control
- Poorly suited to air-vehicle application due to lack of engineering discipline in documentation, etc.

Available piston engines with powers above 50 hp seem to conform better to current aircraft practice, where reliability and quality control in particular are of a higher order.

2.5.6. There exists a need for a new approach towards RPV engines, even in the piston types and especially at power levels below 50 hp to bring these engines into line with common aircraft practice, as well as to improve their performance. These points are discussed in Section 4.

3. REQUIREMENTS ON SMALL RPV's

3.1 Requirements on engine power

In this section some parametric calculations are presented to characterize RPV-vehicles and to assess the requirements for the engine power to be installed.

Three types of vehicles are considered:
- fixed-wing vehicles - conventional configuration
  - delta-configuration
- rotary-wing vehicles

The calculations on the conventional fixed-wing type were especially performed for this study. They are somewhat more extensively presented than the investigations on the other types, which are based on studies performed elsewhere.
All data in this section, however, have to be considered as examples only, illustrating some design trends for small RPV's.

3.1.1. Fixed-wing vehicle-conventional configuration

3.1.1.1. General

The calculations on the conventional configuration are based on the following assumptions:
- the vehicle is non-expendable and has fixed wings (without flaps), normal fuselage, horizontal and vertical tailplanes and fixed undercarriage,
- the vehicle is able to perform conventional take-off and landing maneuvres; special devices are to be used to shorten the distances required for these maneuvres,
- the power loading (take-off weight per horse power) is assumed in comparison with existing vehicles.

3.1.1.2. Weight estimation

The take-off weight of the vehicle is divided into the following weight components:

$$W_{TO} = W_P + W_{EQ} + W_S + W_E + W_F \qquad (3.1)$$

where

W_{TO} = take-off weight
W_P = payload weight
W_{EQ} = equipment weight of vehicle
W_S = weight of airframe structure (including undercarriage and propeller).
W_E = engine weight
W_F = fuel weight

Introducing the specific engine weight $C_E = \frac{W_E}{P_{br}}$ (P_{br} = max. or rated brake horsepower) and the specific fuel consumption $C_P = \frac{F}{P_{br}}$ (F = fuel consumption) in eq. (3.1), the take-off weight for a given endurance E at rated power can be written as:

$$W_{TO} = \frac{W_P + W_{EQ}}{1 - \frac{W_S}{W_{TO}} - \frac{1}{W_{TO}/P_{br}}\left\{C_E + C_P E\right\}} \qquad (3.2)$$

For all vehicles has been chosen a structural weight ratio $\frac{W_S}{W_{TO}} = 0.3$ and a power loading $\frac{W_{TO}}{P_{br}} = 4$ kg/hp ($\sim$ 9 lb/hp; see e.g. Table 1.1).
Three different payloads are considered: W_P = 10,30 and 50 kg (type "A", "B" and "C").
From the engine inventory (Section 2) characteristic values of C_E and C_P are chosen; the equipment weight W_{EQ} has been assumed in accordance with the size of the vehicle.

The following table shows the values assumed:

Vehicle type	Payload W_P (kg)	Equipment weight W_{EQ} (kg)	Engine type	Specific eng. weight C_E (kg/hp)	SFC, C_P (kg/hp-h)
A	10	10	light, 2 cycle	0.30	{ 0.9 (glow-fuel) 0.55 (conv. fuel)
B	30	15	aero, 2 cycle	0.60	0.40
C	50	25	aero, 4 cycle	1.00	0.25

Using these data the take-off weight of the three vehicles are estimated from eq. (3.2) for endurances up to E = 3 hrs. The results are shown in Figs. 3.1 – 3.3, which give also the related weight break-down into the vehicle components and the engine power installed. The power range of RPV-engines considered in this study (10-100 hp) is confirmed by these results. The very steep T.O. weight increase with flight duration for glow-fuel type engines is note-worthy and will limit the application of these engines to 1 hour flight time maximum.

3.1.1.3. Sensitivity factors.

The results presented in Figs. 3.1-3.3 are of course dependent on the assumed engine characteristics.

To show the sensitivity of the take-off weight for specific engine weight and specific fuel consumption, a typical example is given in Fig. 3.4 for a vehicle with 30 kg payload (type "B") and 2 hr endurance.

More generally, one can easily derive from eq. (3.2) the effect of an unit weight change of engine or fuel (due to a change of specific engine weight or specific fuel consumption) at a constant power loading W_{TO}/P_{br}:

$$\frac{dW_{TO}}{dW_E} = \frac{dW_{TO}}{dW_F} = \frac{W_{TO}}{W_P + W_{EQ}} \tag{3.3}$$

This "growth factor" follows directly from Figs. 3.5 – 3.3 and is shown in the table below (engines with conventional fuels only):

$\frac{dW_{TO}}{dW_E} = \frac{dW_{TC}}{dW_F}$	type "A" (W_P=10 kg)	type "B" (W_P=30 kg)	type "C" (W_P=50 kg)
for E = 1 hr	2.05	2.22	2.5
= 2 hr	2.85	2.86	3.08
= 3 hr	4.70	4.00	3.81

This table shows that for a flight time of 2 hrs every pound (kilogram) saved in engine or fuel weight will reduce the take-off weight by about three pounds (kilograms).

3.1.1.4. Wing loading

For a given vehicle lift-drag polar curve the wing- and power-loadings are related with flight speed by the well-known equilibrium conditions for steady level flight:

$$\frac{W}{S} = C_L \tfrac{1}{2} \rho V^2 \tag{3.4}$$

$$\frac{W}{P_{br}} = \frac{\eta\, C_L/C_D}{V} \tag{3.5}$$

For the vehicle to be considered, a parabolic lift-drag polar curve is assumed:

$$C_D = C_{D_o} + \frac{C_L^2}{\pi A e} \tag{3.6}$$

Reasonable values for the variables in these equations are for a vehicle of conventional lay-out:

C_{D_o} = 0.030 (fixed undercarriage)*)

A = 6

e = 0.70 (Oswald efficiency, including effects of lift on drag of all vehicle components)

η = 0.70 (fixed-pitch propeller)

Fig. 3.5 is based on these data and shows the relationship between speed V, wing loading $\frac{W}{S}$ and

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*) C_{D_o} varies with wing area S for a fixed parasite drag area of fuselage tail, etc.; this effect has been ignored.

power loading $\frac{W}{P_{br}}$ for flight at sea level (ISA). This figure applies to maximum level speed and cruise speed for the appropriate values of W/P_{br}. It shows the trade-off between wing loading and power loading for a given flight speed. Based on data of existing small RPV's for the smallest RPV (type "A") a good choice for the wing loading seems: $W/S \approx 25$ kg/m^2. It is considered as a sound design philosophy to increase the wing loading (and speed) with increasing gross weight. Based on this philosophy the wing loading of vehicles "B" and "C" has been chosen:

$\frac{W}{S} = 40$ and 60 kg/m^2 respectively.

3.1.1.5. Vehicle characteristics, based on actual engines.

A further evaluation of the characteristics of the RPV-types "A", "B" and "C" can be made by the introduction of the choice of actual engines.
This will be illustrated for the vehicles with a flight time of 2 hrs (based on rated power and corresponding fuel consumption). From Figs. 3.1 – 3.3 the engine power required is derived and from the Weslake survey (Appendix 2) a suitable engine type has been chosen, as indicated in Table 3.4. Using the same equipment weight and structural weight ratio the weight distribution of the vehicles is found again.
From choice of wing loading already made and the known power loading the level speed is derived from Fig. 3.5 for the rated power (max. speed) and for a cruise power ratio of 70%. Assuming that the fuel consumption per hour is independent of the power setting, the radius of action can also be estimated for a given loiter time at the mission target. The dimensions of the wing follow from wing loading and aspect ratio (A=6). From rough estimates of fuselage and tail dimensions, it has been checked that the zero-lift drag coefficient $C_{D_o} = 0.030$, on which Fig. 3.5 has been based, has been a reasonable guess.
The minimum flight speed of the vehicles is based on the assumption: $C_{L_{max}} = 1.4$ (without high-lift devices). From simple performance calculations the take-off and landings distances for an obstacle height of 15 m (50 ft) has been estimated for conventional take-off and landing techniques.
From these calculations, it has been found that the following simple rules can be derived for the take-off and landing distances of the vehicles considered here:

$$S_{TO}\ (\mathrm{m}) \cong 1.5 \times \frac{W_{TO}}{S}\ (\mathrm{kg/m^2}) \times \frac{W_{TO}}{P_{br}}\ (\mathrm{kg/hp})$$

$$S_L(\mathrm{m}) \cong 4 \times \frac{W_{TO}}{S}\ (\mathrm{kg/m^2}) + 150\ (\mathrm{m})$$

The data in Table 3.1 give an overall impression of the main characteristics, which can be expected for RPV's with conventional configuration, based on existing engine types. The take-off and landing distances in the table indicate clearly that for many applications special launch and recovery techniques will be required in operational environments, where distances of 200-450 m are not available in a suitable prepared condition for conventional take-off and landing techniques.

3.1.1.6. Some propeller considerations.

The choice of the propeller of small RPV's will result from a compromise between vehicle performances, noise considerations and simplicity in design. The latter requirement makes the use of a fixed-pitch propeller preferable.
In the following some general remarks on the matching of the engine and fixed-pitch propeller are given.

Effect of pitch-angle – The fixed-pitch propeller can be matched to a given design engine power and engine speed at one flight speed only. At lower flight speeds the rpm decreases for the same throttle setting, resulting in a lower engine power output. At higher flight speeds the engine is overspeeding with respect to the design rpm. To prevent overspeeding in level flight the pitch angle can be chosen in such a way that at full-throttle the maximum engine speed and rated power are obtained at maximum flight speed (point A in Fig. 3.6). At lower speeds this results in a lower rpm and less than rated power.
If a smaller angle of pitch of the propeller is applied, the engine speed becomes larger at all flight speeds and the maximum rpm is reached at a lower speed than in the previous case (point B in Fig. 3.6). The power available is increased at the lower flight speeds, but to prevent overspeeding the engine has to be throttled at higher flight speeds, resulting in a lower maximum speed in level flight.

Effect of propeller diameter – The propeller pitch-angle corresponding with the design point A in Fig. 3.6 decreases with increasing propeller diameter. This lower pitch-angle results in higher engine rpm's at lower flight speeds and a higher static thrust and power available. This increase of the diameter is limited by the tip Mach number, which must be low enough to prevent a loss in efficiency due to compressibility effects and to limit the propeller noise. The limitation of the propeller diameter is shown in Fig. 3.7 for a tip speed of 255 m/sec (tip Mach number $M_t = 0.75$ at sea level) at the static condition. This graphs holds also for flight speeds up to $V \cong 200$ km/h (55 m/sec, $V << V_t$). In general for design point A the largest diameter is chosen which is allowed from tip Mach number or vehicle lay-out considerations.

Effect of design engine speed – For a given tip Mach number the largest propeller diameter and best low speed performances results from engines with a low design rpm. For small piston engines,

however, high rpm's are often applied to obtain a high engine power with a small displacement volume. The resulting low propeller diameter requires a high pitch angle to absorb the engine power, which is detrimental for the power available at low speeds.
To improve the engine and propeller matching a propeller reduction gear can be applied. Although a direct drive will be favourable with respect to weight, cost and maintenance, some small piston engines with high rpm are designed with a reduction gear (e.g. Hirth F10A, max. engine speed 5000 rpm, gear ratio 1.865, 2.21 or 2.58).

In general the design of propellers for RPV's can be based on existing design techniques. Available systematic design data, however, will apply to larger propellers than used for RPV's and the effect of (lower) Reynolds number on propeller performance data has to be taken into account[x)]. Most available data will also be only applicable to conventional tractor propellers. Other configurations may offer advantages with regard to the design requirements for RPV's. The use of net-recovery techniques and the requirement of an unobstructed field of forward view may lead to the choice of a configuration with a pusher propeller. Also a ducted propeller may offer an advantage to protect the propeller in the recovery phase. It seems questionable whether the application of a ducted propeller is warranted by vehicle performance considerations only.
The use of the less conventional propeller configurations mentioned above, will require a more extensive development program than the application of tractor propellers in case optimum performance is required.

3.1.2. Fixed-wing vehicles - delta configuration

3.1.2.1. General

The calculations on the delta-wing-vehicle are based on the following assumptions:
- expendable missions or net recovery of vehicle
- catapult launch (which probably is the only sensible possibility for tactical operations)
- max. level speed 250 km/h at sea level (ISA+15°C)

Three different missions have been considered:
a) 0.5 h endurance with max. speed
b) 1.0 h endurance with 0.5 h max. speed and
   0.5 h optimum cruising speed (180 km/h)
c) 3.0 h endurance with 1.0 h max. speed and
   2.0 h optimum cruising speed

For these types of missions the delta-configuration is especially suited for the following reasons:
- low-cost structure
- rugged and easy to handle
- good capability for catapult launch and steep dive
- little gust sensitivity
- small surface (low radar cross section and optical signature)
- low structural weight

3.1.2.2. Calculation of the component-weights

The take-of-weight of an air vehicle is given by the weight of its main components:

$$W_{TO} = W_P + W_{EQ} + W_S + W_{PR} + W_F \text{ (kg)} \qquad (3.7)$$

with

W_{TO} = take-off-weight
W_P = payload weight
W_{EQ} = equipment weight
W_S = weight of airframe structure
W_{PR} = weight of propulsion unit (engine plus propeller)
W_F = fuel weight

Payload weight

The payload weight is in the range of 10 to 50 kg. Therefore the calculations will consider payloads of 10 kg, 30 kg and 50 kg.

Equipment weight

All missions considered here, require the same equipment which consists of the following systems:

Navigation and flight control system
- gyro-subsystem
- air-data-subsystem
- control-surface (autopilot with integrated onboard computer for preprogrammed part of flight path plus actuators)
- external navigation subsystem

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x) A study on the correlation between the data of small propellers for RPV's and large scale aircraft propellers is currently performed by H. Borst Associates, Wayne, Pennsylvania, USA and will be available at the end of 1977.

Power-supply-system
- fuel subsystem
- generator and power conversion/distribution unit
- wiring harness, batteries, etc.

Considering the latest technology (micro-miniaturized electronics) the total weight of this equipment is in the range of 10-20 kg and has been chosen as 13 kg for all vehicles considered in this section.

Weight of airframe structure
For delta-wing vehicles with a wingspan between 1 and 5 m and a maximum level speed of 200 to 300 km/h the structure weight can be calculated by the following empirical equation:

$$W_S = 6 \times S^{1.22} \text{ (kg)}$$

where S is the wing area in m^2. This empirical equation is valid for glass-fiber-plastics only. The wing loading has been assumed to be 35 kg/m^2, in order to achieve the above mentioned maximum level speed with a reasonable power loading.

Weight of propulsion unit and fuel
For the first iteration loops an average power/weight-ratio and an average SFC are estimated. Depending on the results the calculation is repeated with an actual engine chosen from the Weslake survey (Appendix 2). According to test runs of KOLBO as well as to test runs of Dornier with a 10 hp-KOLBO engine and with a German 15 hp engine the SFC's at cruising throttle (75%) and full throttle (100 %) are nearly equal.

The weight of the propeller was calculated in the following manner. For efficiency reasons the tip velocity should not exceed a value of about 240 m/s. With this figure the maximum diameter is fixed for a given RPM. The following empirical equation was given by a propeller manufacturer (Hoffmann KG, Rosenheim, Germany) for the weight of a two bladed fixed propeller depending on the diameter:

$$W_P = 0.875\ D_P^{2.73} \text{ (kg)}$$

where D_P is the propeller diameter in m.

If an n - bladed propeller is used, this equation can be changed as follows:

$$W_P = 0.875\ \frac{n}{2}\ D^{2.73} \text{ (kg)}$$

3.1.2.3. Results
With these assumptions the required engine power and the take-off-weight can be computed by conventional aerodynamical design methods.
The results are summarized in Table 3.2 and shown in Figs. 3.8 – 3.10 for payloads of 10 kg, 30 kg and 50 kg respectively.

3.1.3. Rotary-wing vehicles

3.1.3.1. General
The helicopter RPV has been examined in detail, because it provides a means of point observation and surveillance in hovering flight. This capability of hover and the possibility of virtual invisibility of the vehicle, if its size and signatures are small, renders the helicopter RPV of unique importance, with low vulnerability and high resolution capacity.
The vehicles examined are part of the design studies, which supported a current vehicle project. Thus, vehicle weight break-down was derived from these studies, engine choice and performance results from particular engines, or studies of engines, while the general power requirements for the vehicle in terms of its all-up weight and flight speed are derived from the fundamental helicopter equations.
Two vehicles has been considered with a payload of 10 and 30 kg respectively. The following sections present some data on these vehicles.

3.1.3.2. Power requirements
Figs. 3.11 and 3.12 show the curves of engine shaft power required versus flight speed for both vehicles at different all-up weights.
The power curves are estimated according to the basic helicopter expressions:
- hover; hover power required is made-up of rotor-blade profile power and induced power with allowance for tail-rotor and auxiliary power take-off:

$$P_{HOV} = K_2 \left[\frac{\bar{C}_{D_P}}{8}\ \sigma\rho\ AV_T^3 + K_1\ \frac{T^{3/2}}{\sqrt{2\rho\ A}} \right] \qquad (3.8)$$

where:

$\bar{C}_{D_P}$ = mean blade profile drag coefficient = 0.010

σ = solidity

ρ = air density
T = rotor thrust (= weight W + vertical drag)
A = disc area
V_T = tipspeed
K_1 = induced rotor efficiency factor = 1.11
K_2 = power allowances = 1.12

- forward flight; if the blade-profile power is written as P_{PROF}, then power required for forward flight is given by:

$$P_{FL} = K_2 \, P_{PROF} \, (1 + 4.65 \, \mu^2) + K_3 \frac{T^2}{2\rho AV} + \frac{D_s}{q} \, \tfrac{1}{2}\rho V^3 \qquad (3.9)$$

where: $\mu = \dfrac{V \cos \alpha}{V_T}$ (α = rotor angle of attack)

V = flight speed

$\dfrac{D_s}{q}$ = parasite drag area

K_3 = 1.17

3.1.3.3. Vehicle weights

For the two vehicles the all-up weight and the component weight distribution versus flight endurance are shown in Figs. 3.13 and 3.14.
A more detailed weight distribution is presented in Table 3.3 and 3.4 for vehicles with a flight endurance of about 2 hrs.

3.1.3.4. General considerations

The two vehicles considered, and partially summarized in the previous sections, are indicative of the large difference in vehicle power-loadings which can be assigned to rotor-craft. This is shown in Fig. 3.15, where more than a factor of two exists between the minimum power loading required for the maximum forward speed for the large vehicle, and the minimum power loading required to hover for the small vehicle. This variation between loadings results from strictly pragmatic reasons, rather than optimization or parametric indications, for example.
The large vehicle was designed as an operational surveillance vehicle in which rotor size was determined from considerations of engine power available (a function of a particular engine that happened to be available), limiting blade-tip speed (which influences and must be used to minimize acoustic signature), radar reflectivity of the rotor disc, maximum allowable autorotative speed of descent, and other criteria which do not necessarily appear in the fundamental helicopter equations. The choice of body shape arose from considerations less of mission performance (i.e. payload, fuel capacity) than of visual detectability and vulnerability to various defensive weapons.
Further, the choice of engine for this vehicle was a turboshaft engine of the type which could be derived from a current Lucas unit, described in Appendix 6, because this engine resulted in minimum body size, together with minimum rotor radar cross section.
Vehicle choice if it is to represent an optimum solution, should take into account detection by visual means, radar, noise and infra-red emission, the greatest importance is here assigned to visual detection of the vehicle body, and radar detectability of the rotor. These design and operational aspects have defined the characteristics of the large vehicle.
By contrast, the small vehicle was defined as a Demonstrator Vehicle in support of the R and D-programme for an operational vehicle.
This Demonstrator Vehicle was required to demonstrate the basic vehicle concepts of stability and control and to exercise the payload sensors, assigned to the operational vehicle. Thus, considerations of vehicle detection and vulnerability were of no importance in the choice of vehicle design. Rather, the principal parameter involved was that of minimum cost and availability of vehicle components. The resulting vehicle was, therefore, piston-engine propelled and considerably smaller than the Operational Vehicle, while the rotor size was not constrained by the need to minimize radar or acoustic signatures. As a result, the loadings are quite different between the vehicles.

3.2. Conclusions

In the previous sections of this Chapter some results of parametric studies are presented for various types of small RPV's.
It will be evident that such parametric approaches are useful in a very general fashion, for quick filtering of vehicle size, utilizing available engine data. The useful definition of vehicles, in real situations of particular payload sizes, detection and vulnerability concepts, can only result from in-depth vehicle design studies, usually based on available rather than on idealized engines. Such design studies, however, lie outside of the scope of this study.

4. ENGINE REQUIREMENTS AND SPECIFICATION

4.1. Summary of engine requirements

4.1.1. General requirements

In general, the detail engine requirements are adequately covered in the engine specification which is given in Appendix 4. This specification is typical for unmanned aircraft engine practice in the USA and aimed at requirements less demanding and costly than manned aircraft standards. It should

be noted that the specification is general and does not deal with a specific vehicle. The engine specification for a specific vehicle would require definitive requirements in numerous areas which are not adequately covered by the specification in Appendix 4. The wide range of potential applications of the small RPV's creates contrasting requirements from the engine standpoint. The following items are illustrative to this point:

4.1.1.1. Noise

For the battlefield reconnaissance-type mission, it would be highly desirable to have a vehicle with an extremely low noise signature. This would necessitate an engine requirement for noise attenuation devices which could range from simple muffler-type systems to consideration of buried installations. However, it is quite possible that a buried installation would create some problems relative to cooling flow, necessitating installation of some type of forced cooling system on the engine. A contrasting-type mission would be one where the primary purpose of the vehicle is to divert the attention of the enemy troops. A high noise level could be very desirable, inclusive of the type of noise which would be easily recognizable and identifiable. It would appear that the high frequency exhaust noise could be a definite asset for this type mission. Therefore, it is possible that a configuration would be desirable which would augment rather that attenuate the exhaust noise.

4.1.1.2. Ignition system

A single, shielded ignition system would be acceptable from the specification standpoint. However, one of the primary items of concern in small RPV's is the cost of the vehicle. Concentrated efforts are being made to keep the cost at a reasonable level. One significant method of reducing cost of vehicles is to capitalize on high production rates. A high potential for civil application of small RPV's exists for such things as pipe-line monitorship, power-line monitorship, continuous surveillance of cities for police-type action, commercial fishing surveillance-type activity, and many others. These applications include operation over densely populated areas and over water. The RPV's for these type applications would require some type of civil certification. In order to certify civil aircraft for operation over densely populated areas, dual ignition systems are a necessity. Thus, it may be more beneficial to the military to procure a derivative of a commercial engine which would have dual ignition rather than develop a new engine which meets the minimum requirements of a single ignition system. It is also quite possible that in the performance of some missions it would be desirable to operate the vehicle with an unshielded ignition system which could provide an inexpensive electronic interference capability.

The aforementioned comparisons are presented as typical illustrations of the widely diversified requirements which can occur over the range of the small reciprocating engine RPV missions and applications. Therefore, it is generally concluded that there will be no single requirements document which can cover all possible applications of small reciprocating engines to RPV's. However, the specification in Appendix 4, can be used for general guidance for initiation of definitive requirements for a specific RPV engine.

4.1.2. Comparison of existing engines and requirements

As mentioned previously, the specific vehicle requirements are highly dependent upon the mission and require extensive detailed coordination between the propulsion community and the vehicle's requiring agency. An initial attempt was made to analyze each existing engine relative to specific missions. However, the large number of available engines and the numerous detailed requirements - some of which are peculiar to a specific mission - tended to create an infinite number of combinations for analysis purposes. Therefore, the analysis of the existing engines was performed based on the general desired characteristics of the Mini-RPV engines. Those characteristics include:

(1) specific engine weight of approximately 1 lb/hp or less;
(2) specific fuel consumption of less than 1 lb/hp;
(3) low vibration levels;
(4) reliability over the desired engine life, which in general is a fairly short period of time, nominally approximately 20 hours;
(5) ability to operate on standard NATO force ground fuels and lubricants;
(6) some growth potential in order to accommodate increases in vehicle gross weight; and
(7) reasonable cost at least, but low cost highly desirable.

4.2. Research and development

The desired engine characteristics identified in 4.1.2. are not adequately covered for existing engines of the 10-100 hp range and, as a result, there are numerous R & D programs which could be conducted. However, the minimum R & D efforts which should be conducted are characterized as follows in the relative order of priority:

(1) Power class voids
(2) Propulsion system R & D
(3) Vehicle propulsion system optimization

Typical examples of R & D efforts which should be considered in the three areas are defined as follows:

4.2.1. Power class voids

Based on the identified vehicle power requirements which are not adequately filled by existing engines, a separate engine R & D program should be initiated to obtain the desired characteristics defined in 4.1.2. UK and US information indicates that this R & D effort can be accomplished in a fairly short period of time at moderate cost through utilization of existing high-production rate components for small reciprocating engines.

4.2.2. Propulsion system R & D

Characterization of the engine propeller system performance over a wide range of operating conditions is required in order to provide the aircraft designer with adequate information for vehicle

design purposes. These activities include, but are not limited to the following:

(1) Engine propeller performance with propeller optimized for:
   (a) static thrust
   (b) cruise thrust
   (c) variable pitch

(2) Environmental effects:
   (a) temperature
   (b) pressure
   (c) humidity

(3) Carburization:
   (a) single
   (b) multi
   (c) altitude compensation

(4) Exhaust system:
   (a) tuned
   (b) attenuated

(5) Special tests:
   (a) electromagnetic interference (EMI)
   (b) infra-red characteristics (IR)
   (c) noise
   (d) accessory loading sensitivity

4.2.3. Vehicle propulsion system optimization

Upon identification of the specific vehicle propulsion configuration and the completion of the aforementioned R & D efforts, specific propulsion R & D optimization tests should be conducted on the propulsion system (engine accessories, propeller, fuel system, and simulated installation) in the following areas:

(1) cooling requirements over operating spectrum
(2) EMI, noise and IR
(3) propulsion system performance over operating spectrum
(4) environmental conditions:
   (a) temperature
   (b) pressure
   (c) humidity

4.3 Engine analysis

A review of the existing engines in the power range from approximately 10 to 100 hp reveals a fairly distinct break point at approximately 50 hp. There are engines available above 50 hp which have the desired characteristics. These engines are predominantly production engines for small aircraft or, in certain cases, they are older engines which are currently out of production. In the event there is a specific requirement, the roduction of these older engines could be initiated in a fairly short time. The detailed designs are available and, in certain cases, the production tooling for the engines is still available. Therefore, it is concluded for the power range above 50 hp a derivative of an existing engine or an existing out-of-production engine can be utilized to satisfy the RPV requirements with no significant problems. In the power range below 50 hp there is a fairly large number of engines; however, a detailed investigation of each of the engines reveals some major characteristics which are not desirable. The large number of the candidate engines are single cylinder, two-cycle engines which have been developed for Go-Carts, snowmobiles, chainsaws, etc. This group of engines exhibits a high level of vibration and the quality control is not that commensurate with aircraft practices. The high production rates have resulted in one desirable characteristic: an extremely low cost. There is another group of engines which is considered somewhat special-purpose engines represented by the KOLBO series, a 5 hp four-cycle engine developed specifically for aircraft application, etc. Due to limited production and other factors, these engines are extremely costly - in some cases ranging as high as $5,000 per hp on limited production quantities.

Based on the analysis of the existing engines, it is concluded that there are existing engines which will provide power to meet the requirements of the known missions. However, engines below 50 hp will have numerous undesirable characteristics which should be addressed to. In the USA a program is initiated to address the resolution of these problems for small RPV propulsion systems. This program consists basically of capitalizing on the high production rates of components of engines less than 50 hp and integrating these components into multi-cylinder engines which tend to eliminate the vibratory problem. The program establishes a reasonable limit to the baseline engine piston speed so that there is a limited growth capability in the engine through speed increases. The power level selected for the initial program is 20 hp, with a growth capability to 25 hp in the same basic engine. The same approach could be applied to engines of smaller or larger size. It is concluded that this approach will provide engines in the power range below 50 hp, which will have the desired characteristics. Pertinent information pertaining to the engines which will be developed to meet the US 20 hp requirement is shown in Figs. 4.1 and 4.2, respectively.

5. CONCLUSIONS

5.1. General

5.1.1. In this study attention is mainly given to the several engine types, potential applicable to small propeller-driven Remotely Piloted Vehicles (Mini-RPV's). Their suitability for this application has been studied with regard to engine performance, state of the art, availability and potential for development.

Other parts of the propulsion system, such as the power supply and the propeller, have not been considered in detail. These components might require further attention, e.g. the matching of propeller and engine and the performance of small size propellers for which only limited experimental data are available.

5.1.2. From a mission survey the payload range of small propeller-driven RPV's was established from 10 to 50 kg and flight endurances up to 3 hours. For this range of payloads and flight times some results of parametric and design studies are presented in this report for fixed wing RPV's (conventional and delta wing lay-out) and for rotary wing RPV's. From these data it can be concluded that engines in the power range from 10-100 hp will suit the requirements of small propeller-driven RPV's with all-up weights between 40 and 300 kg.

5.2. Reciprocating two- and four stroke piston engines.

5.2.1. From an inventory of existing piston engines the following typical performance characteristics are derived, based on rated power:

a. two-stroke engines (10-20 hp)
   specific weight : 0.3 - 0.4 kg/hp (0.65 - 0.9 lb/hp)
   specific fuel consumption,
   glow fuel : 0.9 kg/hp-h (2.0 lb/hp-h)
   conv. fuel : 0.55 kg/hp-h (1.2 lb/hp-h)

b. two-stroke engines (20-100 hp)
   specific weight : 1.0 - 0.5 kg/hp (2.2 - 1.1 lb/hp)[x)]
   specific fuel consumption : 0.4 kg/hp-h (0.9 lb/hp-h)

c. four-stroke engines (40-100 hp)
   specific weight : 1.5 - 1.0 kg/hp (3.3 - 2.2 lb/hp)[x)]
   specific fuel consumption : 0.25 kg/hp-h (0.55 lb/hp-h)

These basic engine characteristics will be acceptable for most RPV-applications. It should be noted, however, that the (very light) glow-fuel engines are handicapped by a high specific fuel consumption and the requirement of a special fuel, not normally available to the military user.

5.2.2. The inventory of existing engines shows that many two- and four stroke piston engines are available in the suitable power range for short duration, low-power RPV's (10-100 hp). Most or all of these engines are, however, unsatisfactory from many viewpoints and need all-round improvement in off-design performance, reliability, quality control, carburation, ignition, noise, vibration, etc. This will require both an RPV Demonstrator Engine Programme and supporting component research. This applies especially to the two-stroke engines, up to a rated power of 50 hp, of which a great variety of types are commercially available for non-aeronautical applications (Go-Carts, snow mobiles, chain saws, etc.).
In the range of 50-100 hp some engines are available, which are designed for light aircraft use and these are better suited for RPV application, although most of them are not of modern design and some are even out of production.

5.2.3. A typical new approach is to design an RPV-engine from components of existing, catalogued reciprocating engines. This results into a design and fabrication of a proto-type engine of a choosen horse power (up to 100 hp) in a period of 3 to 6 months at low costs. Such an engine can be ready for flight tests in a further 6 to 9 months, although a development program up to qualification in an RPV (with expensive equipment) might require several years in total.

5.2.4. The desired characteristics for piston engines suitable for application to small RPV's can be summarized as follows:

- specific weight $\leq$ 0,45 kg/hp (1 lb/hp)
- specific fuel consumption $\leq$ 0,45 kg/hp-h (1 lb/hp-h)
- low vibration level
- reliability over the desired (relative short) engine life.
- ability to operate on standard NATO ground force fuels and lubricants
- some growth potential in power
- reasonable low costs

An engine specification is attached to this study, which gives generalized requirements for RPV-piston engines (Appendix 4).

5.2.5. RPV-engine costs are currently indicated in the range of \$500 - \$5000 for a typical 20 hp two-stroke piston engine. The objective for an engine meeting the proposed specification (Appendix 4) is to stabilize the unit costs of a production engine at less than \$1000.-.

5.2.6. The development of RPV-engines can be based on available engineering practice in aeronautics. For instance, it has been found from practical experiences in the USA, that the shielding for electro-magnetic interference of the conventional piston engines with spark ignition can be solved with existing techniques. Thus it will not be necessary to favour the choice of engines without this type of ignition for RPV-applications. Also a V-belt drive has been used for the electrical alternator in case no suitable power drive connection is available on the piston engine.

5.3. Turbo-shaft and other engine types

5.3.1. For some applications in fixed or rotary wing RPV's the turbo-shaft engine might offer advantages, such as low vibration and high reliability. Turbo-shaft engines of power below 100 hp for flight propulsion have not been developed. Design studies indicate that the technology for small turbo-shaft engines in the power range of 30-100 hp can be derived from existing APU practice, although component research to improve the efficiency of compressors and turbines (e.g. minimizing the effect of clearances) might be required.

[x)] In this power range the specific weight decreases with increasing rated engine power.

5.3.2. Only very limited data are available on special types of propulsion devices, like electrically-driven propellers, rotary-piston engines, pressure-jets, etc., and it is not possible to judge their potentials for application to RPV's on the base of the documentation or experience available.
The laboratory work on Stirling engines indicate some attractive features of this engine types for several applications. Due to weight and complexity, this engine type seems to offer little promise for RPV's in the foreseeable future.

6. RECOMMENDATIONS

6.1. To develop suitable small piston engines, in the power range up to 50 hp, for operational use in propeller-driven RPV's the execution of a Demonstrator Engine Program and supporting component research has to be recommended strongly.
The component research, primarily directed to improvements of fuel-metering and control systems, exhaust silencers and ignition systems should be undertaken concurrently with the engine program. The alternator which provide the electrical power supply for the vehicle, also requires further improvement.

6.2. The advantages of turbo-shaft engines, such as low vibration and high reliability, warrant further study of this engine for application to RPV's. Demonstrator Programs will be required to develop this engine type in the power range of 30 to 100 hp for operational use.

6.3. Firms, in the field of low-power piston engines should be encouraged to develop higher quality engineering practices with regard to the engines for propeller-driven RPV's.

6.4. Commonality of applications of small propeller-driven RPV's, suitable for military and civil use should be studied for definition of all common system components related to the vehicle, engine, equipment, ground station and data link. These studies will increase the understanding of operations, reduce component costs and increase reliability, common to military and civil programs.

6.5. Within the scope of this study, it was not possible to define the state of the art and to indicate potential improvements to be made for specialized propulsion systems, such as electrically-driven propellers and pressure-jet driven rotors. No established missions seem to be defined, which indicate firm requirements for these systems. The study of these special propulsion systems and their possible application to specific missions is recommended as a future Working Group activity of the PEP Panel.

Type	$Li\text{-}SO_2$	$Li\text{-}F_eS$	Na-S	Ag-Zn	Ag-Zn	Ni-Zn	Ni-Cd	Thermal	Pb-acid
Operating mode[1]	primary	secondary	secondary	primary	secondary	secondary	secondary	primary	secondary
Operating temp., °C	ambient	400	300	ambient	ambient	ambient	ambient	variable	ambient
Energy density, watt-hrs/lb	150	40-50	40-50	70	50	30	15	13	12
Total weight, lb	5-7	15-20	15-20	10-12	15-17	25-30	~50	57-60	~65
Electrolyte type	non-aqueous	molten salt	solid	aqueous	aqueous	aqueous	aqueous	molten salt	aqueous
State of development[2]	xx	x	x	xxx	xxx	xx	xxx	xxx	xxx

1) Primary - nonrechargeable; secondary-rechargeable.
2) Legend: x - in development
xx - could be available if demand warrants
xxx - commercially available

Table 2.1: Summary of battery characteristics applicable to possible RPV use
Power: 1 - 1½ hp (745-1120 Watts) for 1 hour.

Prime contractor	Designation	Mission	Overall length (less booster) (ft)	Overall span (ft)	Body diameter (ft)	Launch weight (less booster) (lb)
Ford Aerospace ¢ Comm. Corp.	Praeire 2b	Recon ¢ targeting	11.0	13.00	1.0	130
	Calere 3	Recon ¢ targeting	8.0	11.00	1.0	59
Astro Flight Inc.	7212	Recon	2.3	8.0	0.5	23.5
	7312	Recon	6.0	12.0	1.0	80
	7404	Recon	15.0	32.0	2.0	25
	1012 T	Trainer	4.0	6.0	0.5	12
Development Sciences Inc.	Sky Eye 1	Recon	5.5	11.5	1.0	50-120
	Sky Eye 2	Recon, target	6.5	12.35	1.25	50-150
	OWLC,RRPV	Oblique wing research	13.7	22.5	2	800-1000
	Scout	Recon,weapon delivery	4.5	9.0	0.5x1	45-60
Eglen Hovercraft Inc.		Target ¢ recon	6.0	10.0	0.8	33
E-systems Inc. Melpar Div.	E-45	Recon/EW	8.0	8-10	-	50-60
	E-75	Harassment	7.0	10.0	0.7	75
	E-85 X	Commercial/ Test bed	7.5	8-10	-	85-100
	E-100 X	Recon/EW	9.0	10-12	1.0	100-120
Lockheed Missiles ¢ Space	Aequare	Strike support	9.0	12.0	1.0	150
	XMQM-105 (Aquila)	Battlefield support	6.0	12.0	1.0	120
	RTV-2	Research test vehicle	13.5	15.0	1.25	360
	Harassment Drone	RPV with strike capability	8.0	7.0	0.8	60-80
McDonnell Douglas Astronautics Co.	Mark 2	Recon/Targeting	7.0	10.0	0-void 1x2	125
	Acquiline	Recon	5.0	9.0	1.0	80
Northrop Corp.	Electric Mini RPV	Surveillance, attack	4.0	10.0	0.6x1,2	55
	Low Cost Expendable Harassment Vehicle	Mini RPV to harass radar	4.2	8.0	0.9	90
Teledyne Ryan Aeronautical	Star	Acquis, Recon	5.2	7.5	delta	120-140

Table 1.1.: Some data of small U.S. Remotely Piloted Vehicles.
(Ref. Aviation Week / Space Technology, March 21, 1977, pg. 120, 121).

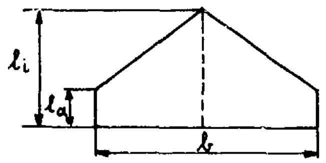
Powerplant	Power loading (lb/hp)	Guidance	Speed (mph)	Endurance or range	Remarks
1 Kolbo Korp D 274, 8 hp	16.25	Radio command	85, max	4+ hr	TV reconnaissance or laser designation
1 Kolbo Korp D 238, 5 hp	11.18	Radio command	85, max	2 hr	Thermal imager utilized for reconn/ laser designation
3 Astro 25 Electric with silver zinc batt.	-	Radio command	75	80 min 50 nm	Flying wing
2 Astro 25 Electric with lithium batt.	-	Radio command	75	2 hr 150 nm	½ scale model
1 Astro 40 Special with solar array	-	Radio command	15-100	-	Altitude up to 60,000 ft
2 Astro 40 with nickel cadmium batt.	-	Radio command	85	30 min	Pilot production
1 McCulloch 101 M/C, 10 hp	5-12	Radio command/ opt. autopilot	40-100	3 hr	Pusher, swept wing, composite material construction
1 McCulloch 101 M/C, 10 hp or 1 Kolbo Korp, 10 hp	5-15	Radio command/ opt. autopilot	40-110	6 hr	Lower radar signature version of Sky Eye 1, larger payload capacity, Kevlar construction
1 McCulloch, 90 hp	8.9-11.1	Radio command and autopilot	80-100	1 hr	Research vehicle
1 Western Gear Electr. 1,25 hp or 1 hp Super Tiger	-	Radio command/ opt. autopilot	40-60	3 hr	Originally for testing electrical propulsion, now potential Kamikaze
1 Kolbo Korp, 3 hp	11	Radio command	125	1-2 hr	-
1 Roper, 4 hp	12.5-15	Full autopilot	55	300 min	Real time control or preprogrammed
-		Autopilot/navigation	-	-	Development prototype (very low Cost Expandable Harassment Vehicle)
18 hp	[illegible]7-5.6	Full autopilot	100	3-5 hr	Real time command and control, preprogrammed
1 Ross, 10 hp	10-12	Autopilot	70	240 min	Exp.; real time command and control guidance
1 McCulloch, 12.5 hp	12	Radio command	115	120 min	Feasibility RPV for long-range surveillance and laser target designation
1 McCulloch, 12.5 hp	9.6	Radio command	120	2 hr	Total system demonstrator
1 Marine Corp rotary engine RC-B-45 hp	8.0	Radio command	130	2 hr	Twin boom pusher with tricycle gear
1 Kolbo Korp D 278	-	Develco Omega navigator	60 kt (cruise) 200 kt (dive)	6 hr	Low manufacturing costs, inexpensive systems, simple field assembly
Ross-engine	-	Radio command	100 kt	3 hr	Configuration optimized for minimum observables
1 Lycoming engine	-	Omega	65	300 nm	Long range
1 electric, 1.25 hp	-	Radio command	80	30 min	Investigate electric power mini RPV's
gas engine Kolbo Korp. Mod D27Y	-	Program & command	120	5 hr	-
2 McCulloch 25 hp	2.4-2.8	Program & command	90 kt	2 hr	Rail launch / net recovery

	Vehicle type	"A"	"B"	"C"
Engine	Engine type	McCulloch Mc 101 B	Kohler BK-340-2AS	Franklin 2A-120-CD
	Engine power (hp)	14	34	60
Weights	Payload (kg)	10 (17%)	30 (21%)	50 (21%)
	Equipment (kg)	10 (17)	15 (10)	25 (11)
	Engine (kg)	5.6 (10)	29 (20)	40 (17)
	Fuel (kg)	15 (26)	28 (19)	49 (21)
	Structure (kg)	17,4 (30)	44 (30)	70 (30)
	T.O. Weight (kg)	58.0 (100%)	146 (100%)	234 (100%)
Loadings	Wing loading (kg/m^2)	25	40	60
	Power loading (kg/hp)	4.17	4.29	3.90
Dimensions	Wing area (m^2)	2.32	3.65	3.90
	Aspect ratio	6	6	6
	Wing span (m)	3.73	4.68	4.84
Performance, ISA-sea level	Max. speed (km/h)	198	226	264
	Cruise speed (km/h)	172	198	230
	Rad. of action (km)+)	129	148	177
	Min. speed (km/h)	61	77	94
	Take-off distance (m)	150	245	[illegible]
	Landing distance (m)	245	305	305

+) Assumed: cruise speed for 1½ h and ½ h above mission target.

Table 3.1 : Vehicle characteristics for RPV-conventional configuration (flight endurance E = 2 hrs).

Payload (kg)	Endurance (h)	T.O. weight (kg)	Engine power P_{br} (hp)	Wing area (m^2)	Wing span b(m)	Length ℓ_i (m)	Chosen engine/max. power
10	0.5	35	7.3	1.00	1.41	1.26	KOLBO D 274/12 hp
	1.0	39.5	8.3	1.15	1.51	1.35	KOLBO D 274/12 hp
	3.0	67.2	14.0	1.90	1.95	1.73	KOLBO D 2100/15 hp
30	0.5	65.2	14.0	1.90	1.95	1.73	KOLBO D 2100/15 hp
	1.0	73.5	15.2	2.10	2.05	1.82	KOLBO D 2100/15 hp
	3.0	104.8	21.7	3.00	2.50	2.13	LOYD LS 400/22 hp
50	0.5	118.8	23.1	3.20	2.53	2.25	SACHS SA 340/23 hp
	1.0	132.5	27.5	3.80	2.72	2.48	KOHLER SK 340-2AS/34 hp
	3.0	161.6	34.0	4.70	3.07	2.73	KOHLER SK 340-2AS/34 hp



$\frac{\ell_a}{\ell_i} = \frac{1}{8}$; aspect ratio A = 2

max. wing loading: 35 kg/m^2

Table 3.2 : Vehicle characteristics for RPV-delta configuration.

Propulsion weight:		29 lb (27,4%)
engine/clutch/fan	12.5 lb	
rotor-blades and hub	6.5 lb	
gearbox and shaft	10.0 lb	
Structure weight:		14 lb (13,2%)
basic structure	4.5 lb	
undercarriage	3.0 lb	
controls/actuators	6.5 lb	
Equipment weight:		21 lb (19.8%)
alternator/regulator	6.0 lb	
computer/amplifier	7.0 lb	
3-axis rate gyro	2.0 lb	
bar. altimeter	1.0 lb	
instrumentation	3.0 lb	
wiring/sockets	2.0 lb	
Payload (10 kg)		22 lb (20,8%)
Fuel		20 lb (18,8%)
All-up weight		106 lb (100%)

Table 3.3 : Weight distribution of small rotor-wing vehicle.

Propulsion weight:		58.0 kg (29%)
engine	24.9 kg	
rotor blades and hub	17.2 kg	
gear box and shaft	15.9 kg	
Structure weight:		36.7 kg (18.4%)
basic structure	9.1 kg	
undercarriage	6.3 kg	
controls/actuators	12.2 kg	
radar absorber	4.6 kg	
fuel/oil systems	4.5 kg	
Equipment weight:		20.5 kg (10.2%)
alternator/regulator	4.6 kg	
flight electr./avionics	15.9 kg	
Payload		30.0 kg (15%)
Fuel		54.8 kg (27.4%)
All-up weight		200 kg (100%)

Table 3.4 : Weight distribution of large rotor-wing vehicle.

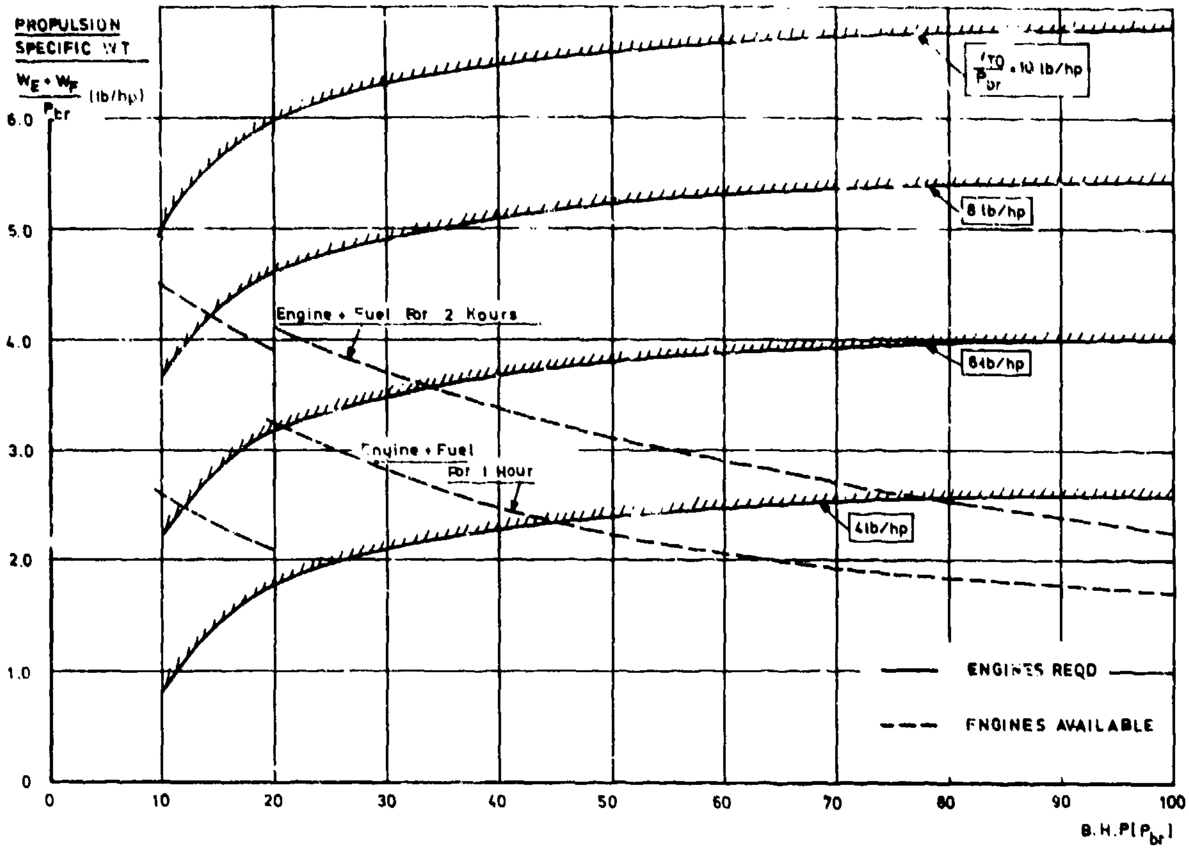


Fig.2.1 Propulsion specific weight; payload $W_p = 20$ lb

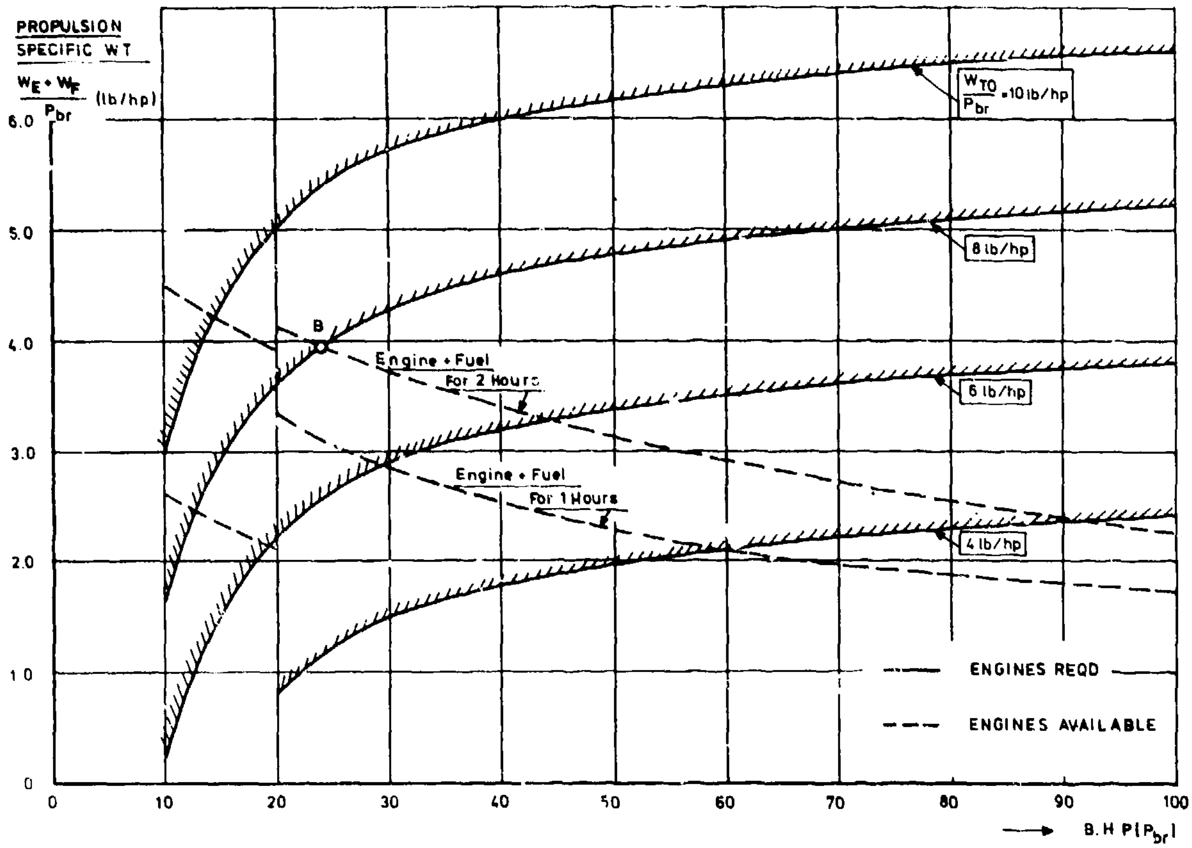


Fig.2.2 Propulsion specific weight; payload $W_p = 40$ lb

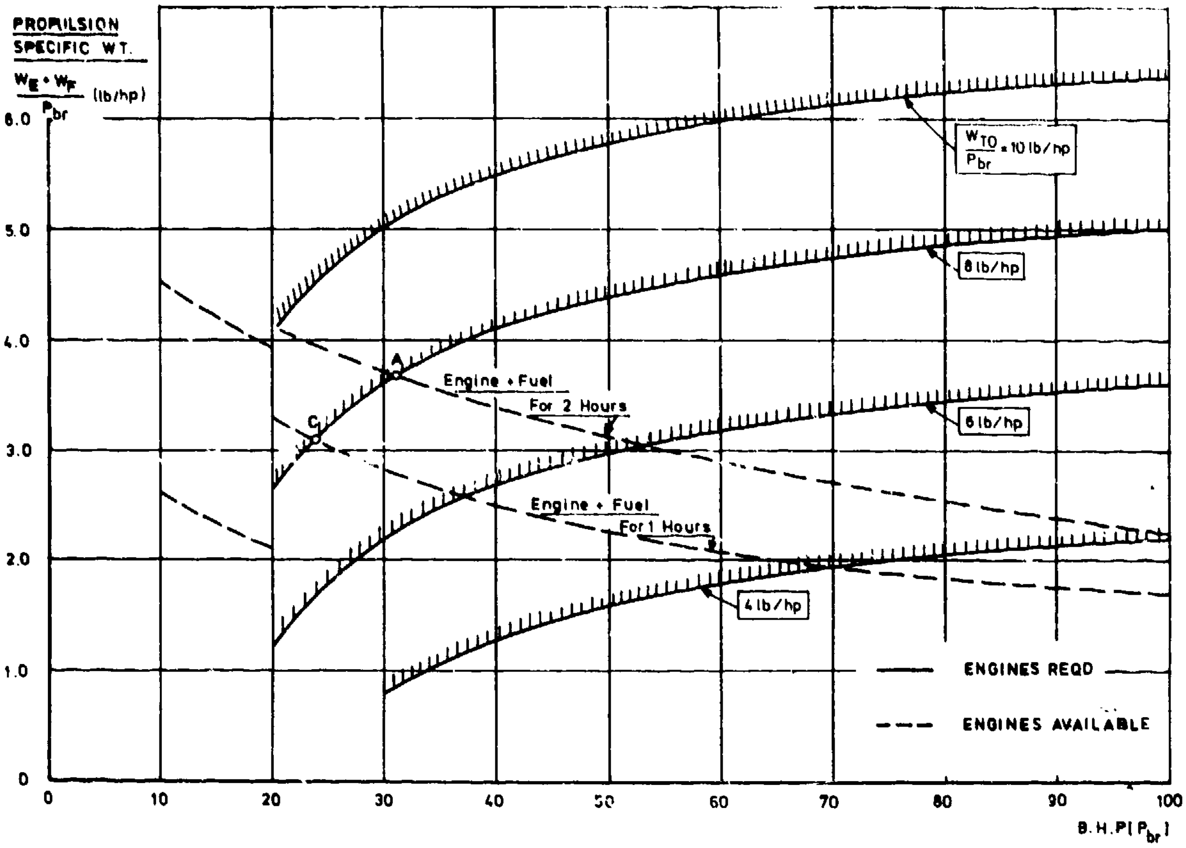


Fig. 2.3 Propulsion specific weight; payload $W_p = 60$ lb

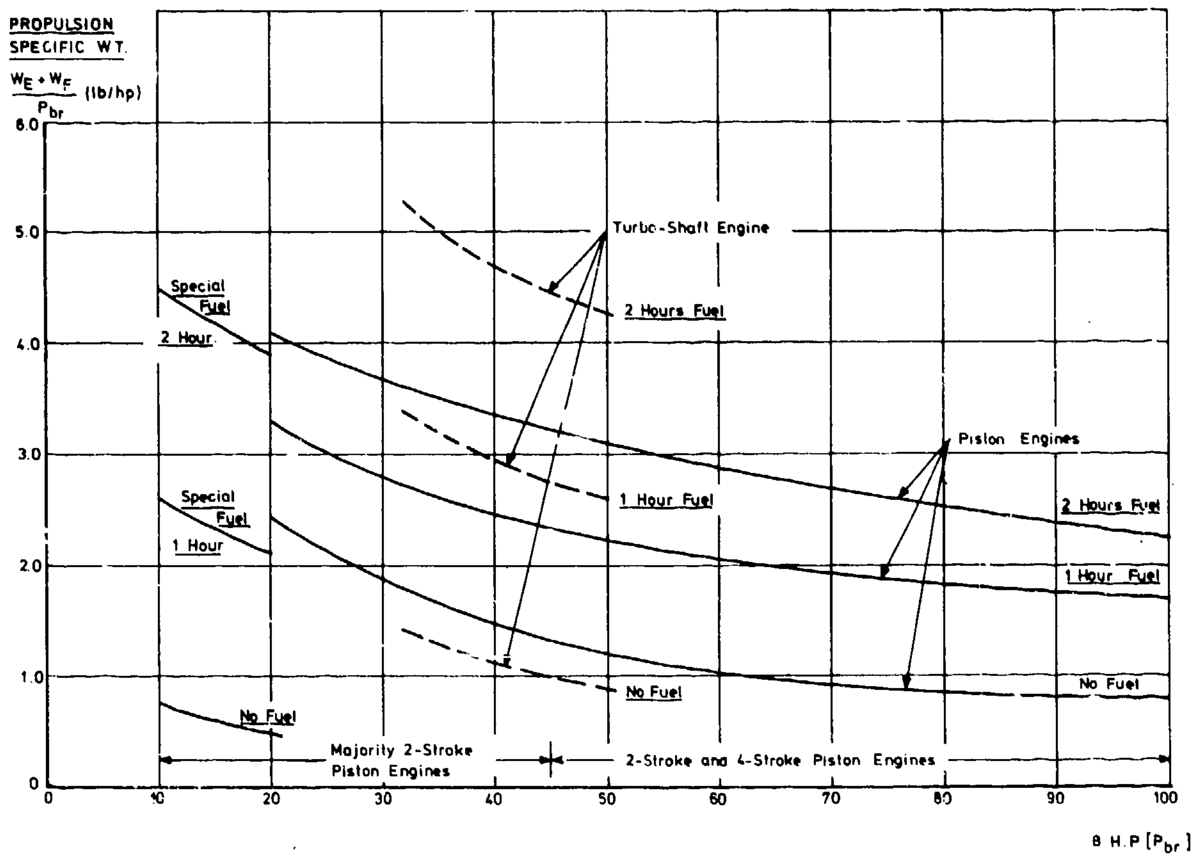


Fig. 2.4 Propulsion specific weight for current engines

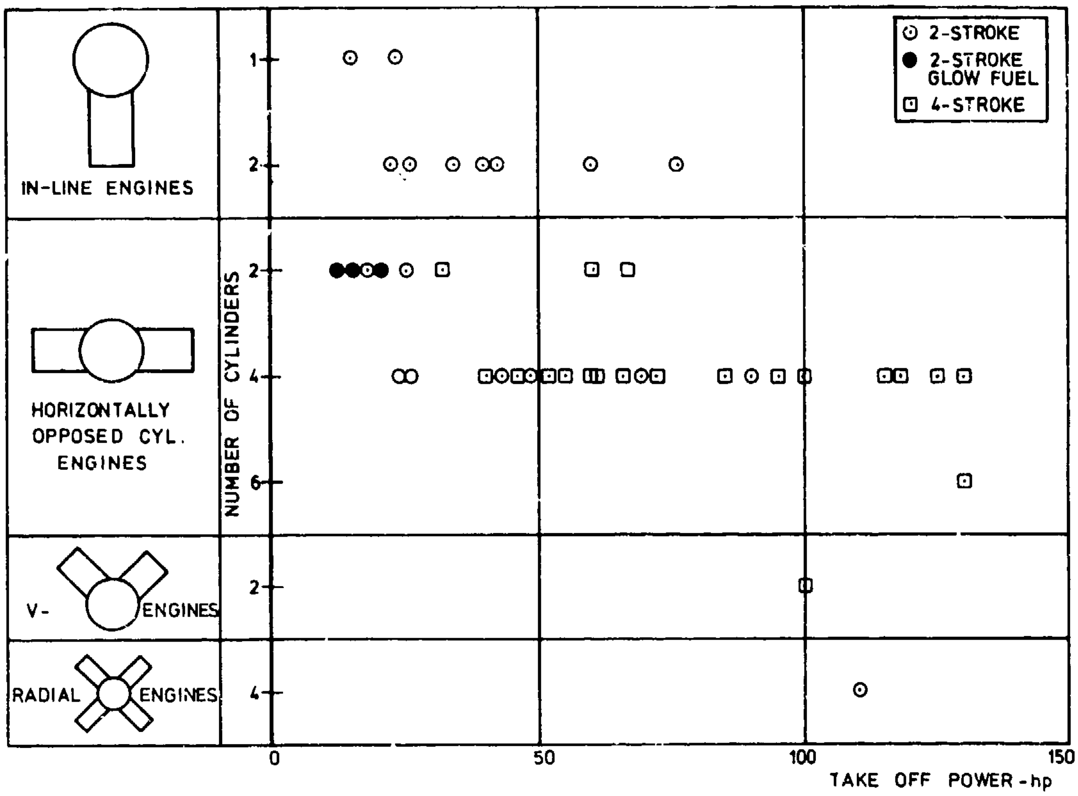


Fig.2.5 Classification of available piston aero-engines

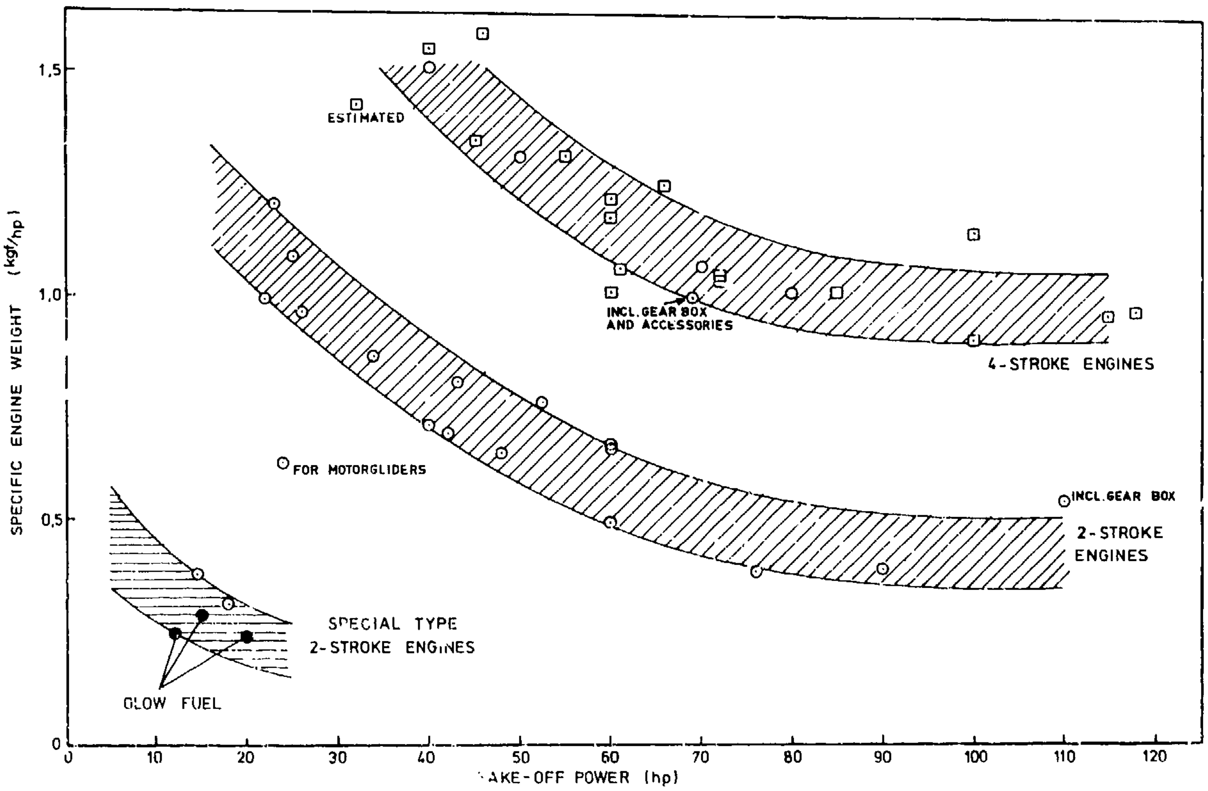


Fig.2.6 Specific engine weight versus take-off power

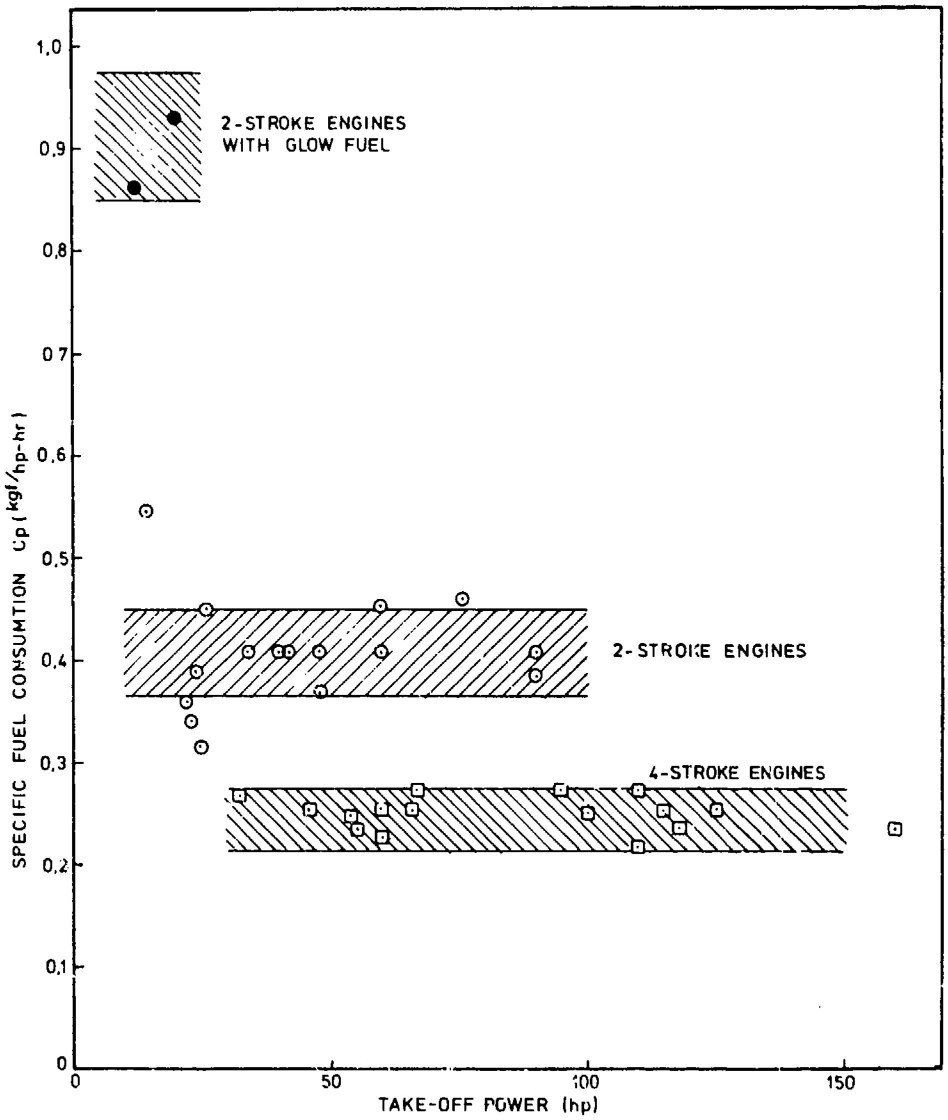


Fig. 2.7a Specific fuel consumption versus take-off power

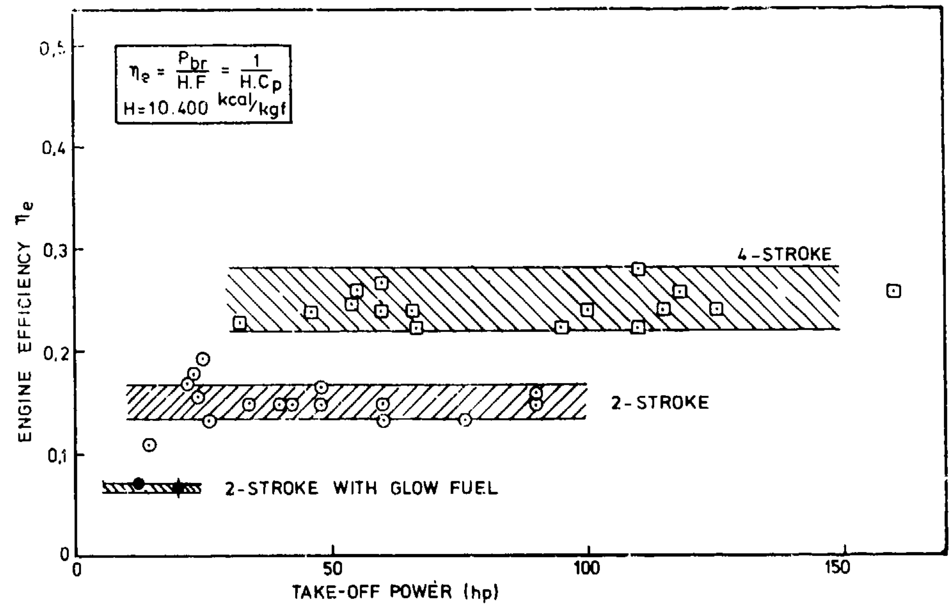


Fig. 2.7b Overall efficiency versus take-off power

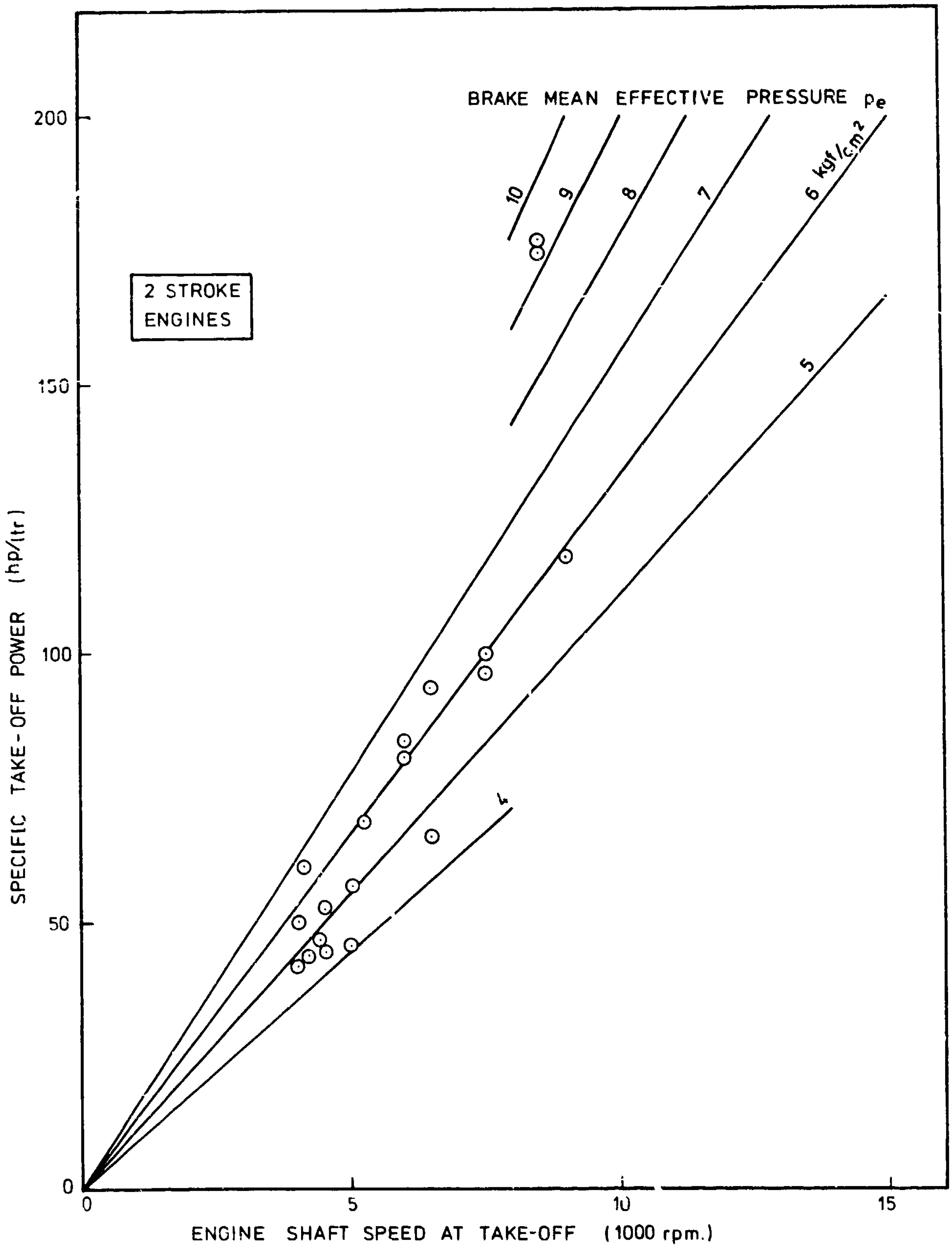


Fig.2.8a Specific power, shaft speed and brake mean effective pressure

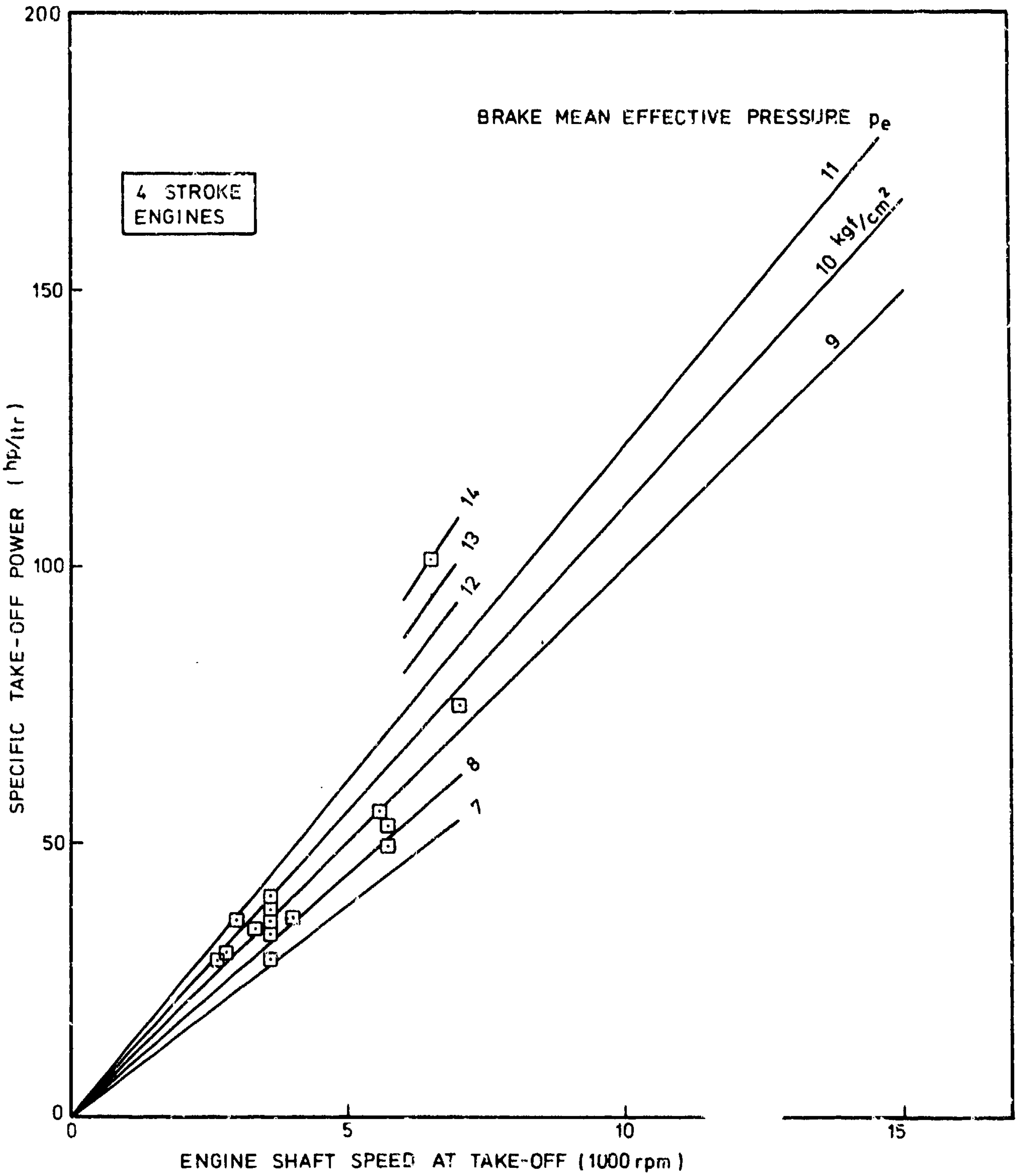


Fig. 2.8b Specific power, shaft speed and brake mean effective pressure

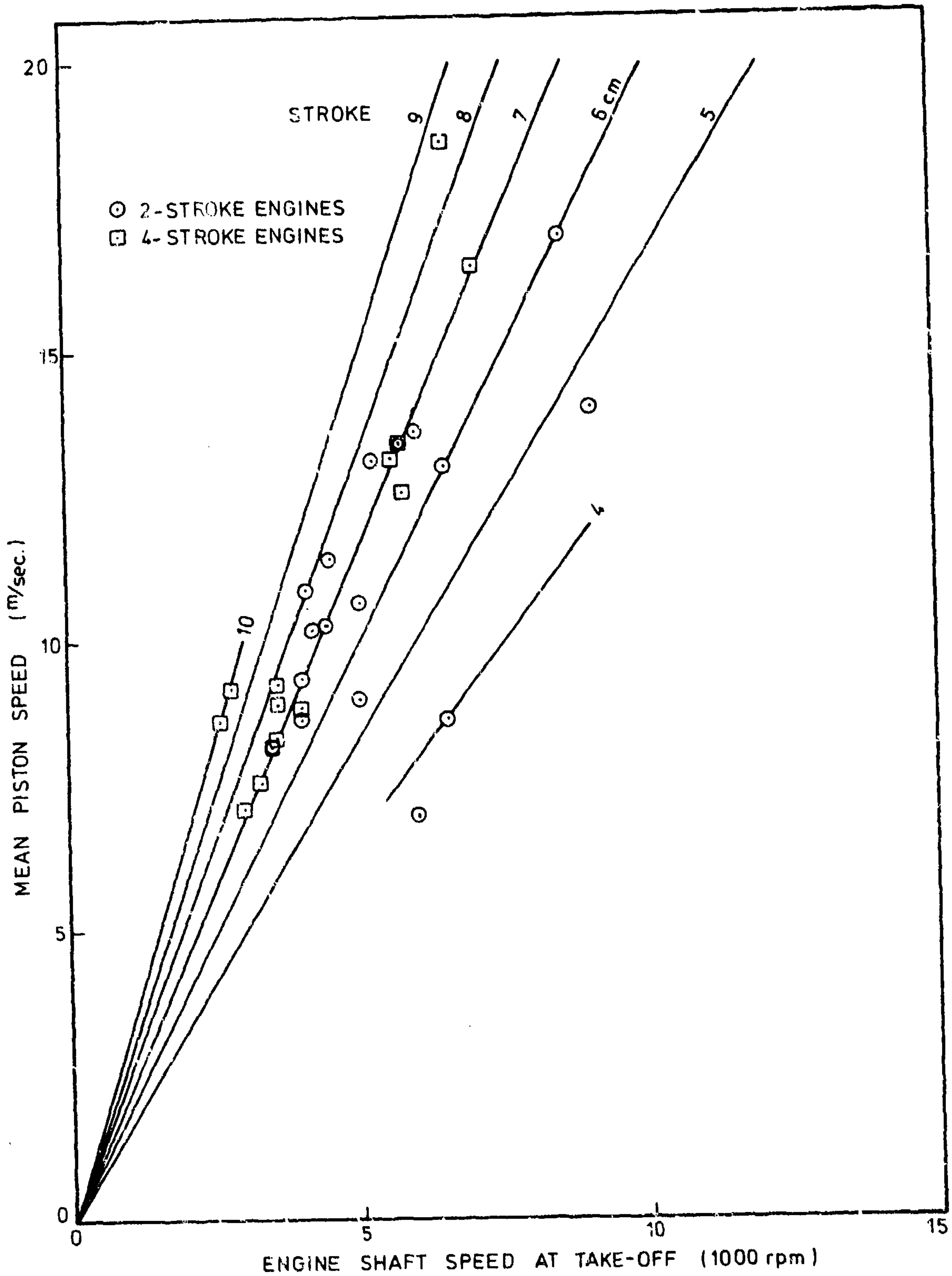


Fig.2.9 Mean piston speed, engine shaft speed and piston stroke length

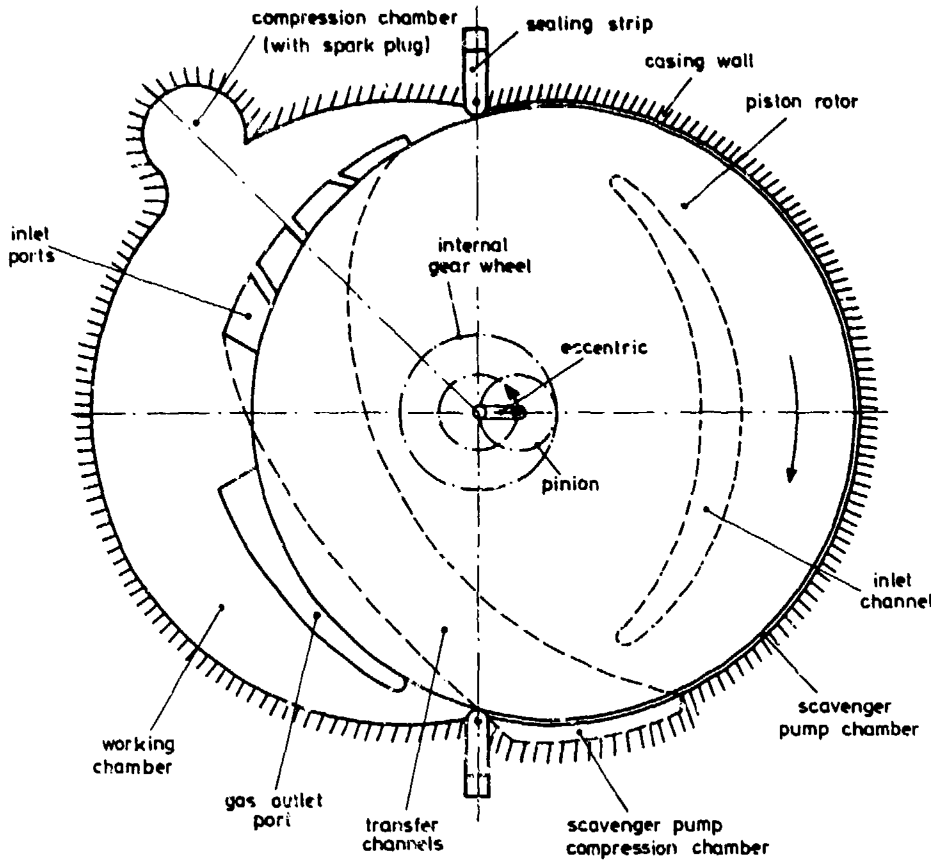


Fig.2.10 Huf-Dornier system for two-stroke engine (schematic)

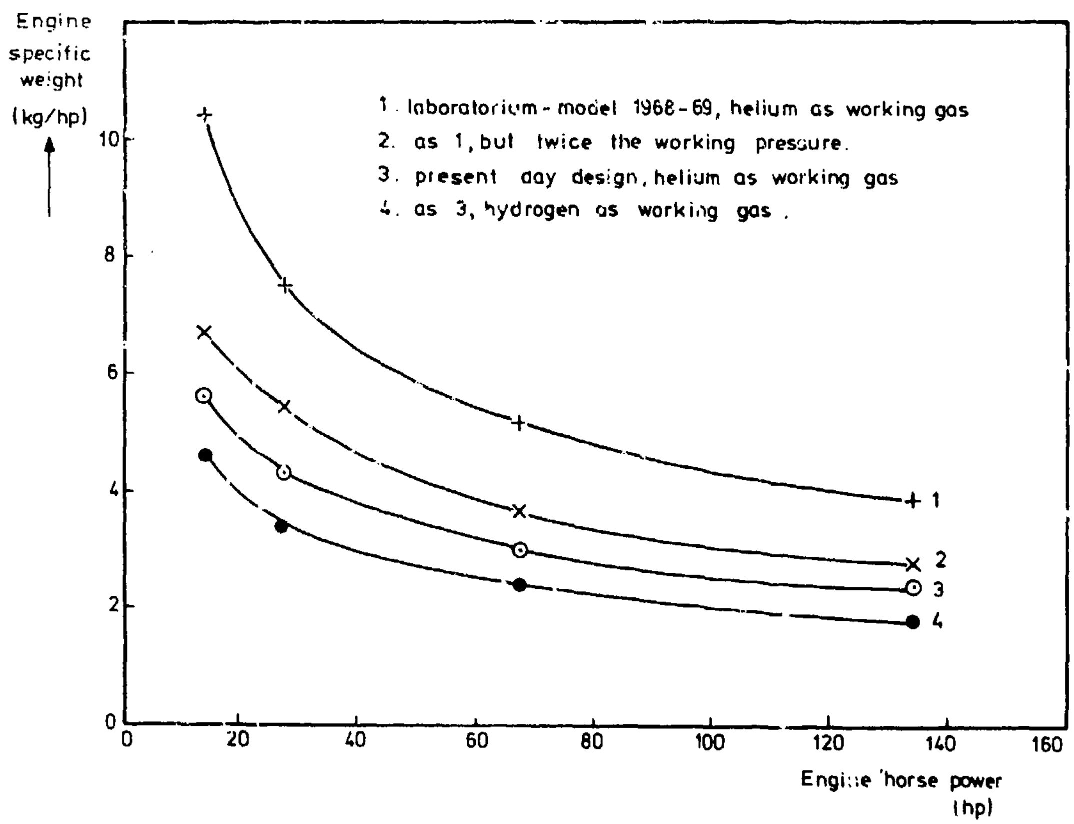


Fig.2.11 Specific weight of Stirling engines
(based on Philips Techn. Review, vol 31, no 5/6, pg 175)

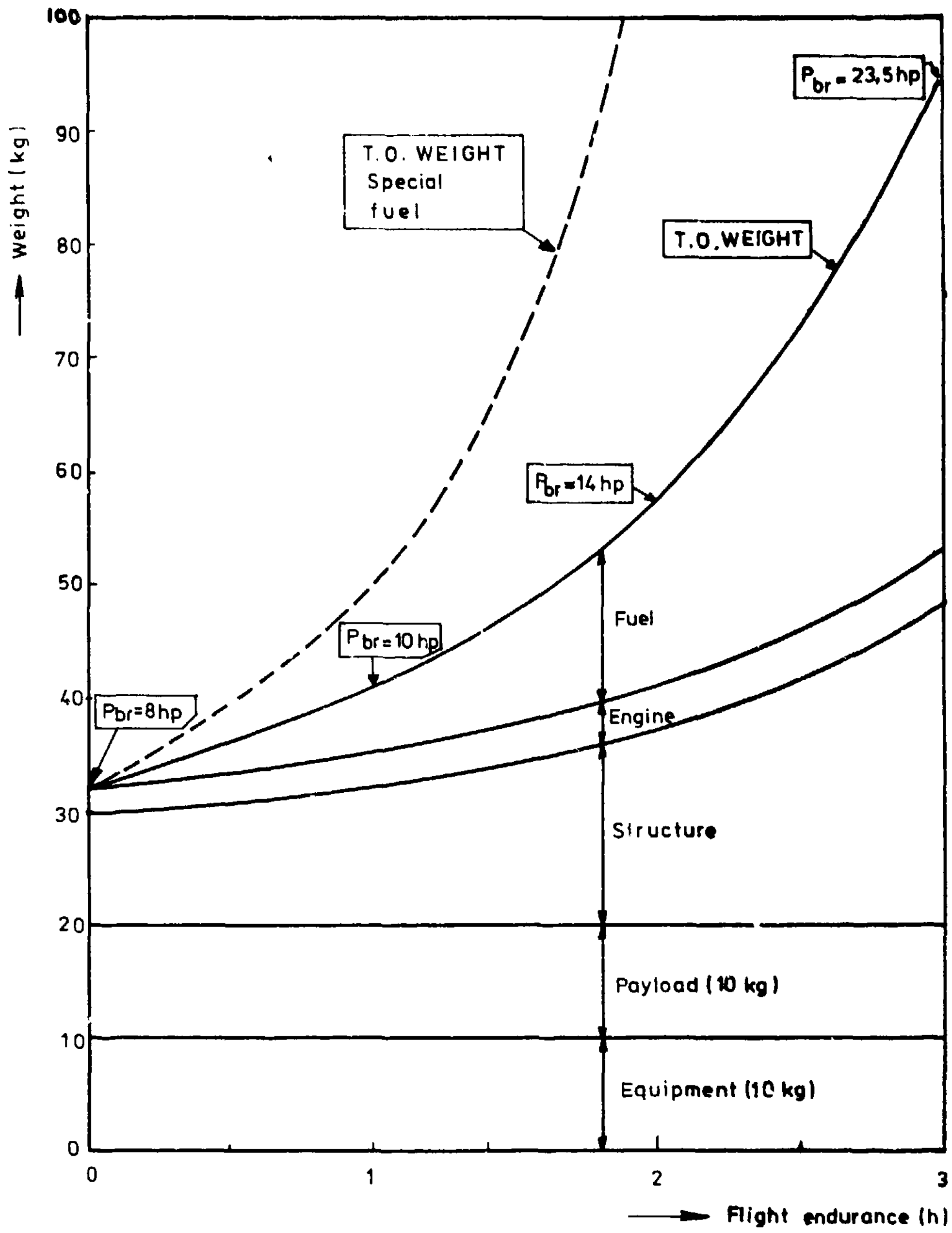


Fig.3.1 Vehicle weight vs. flight endurance for 10 kg payload; RPV-conventional configuration

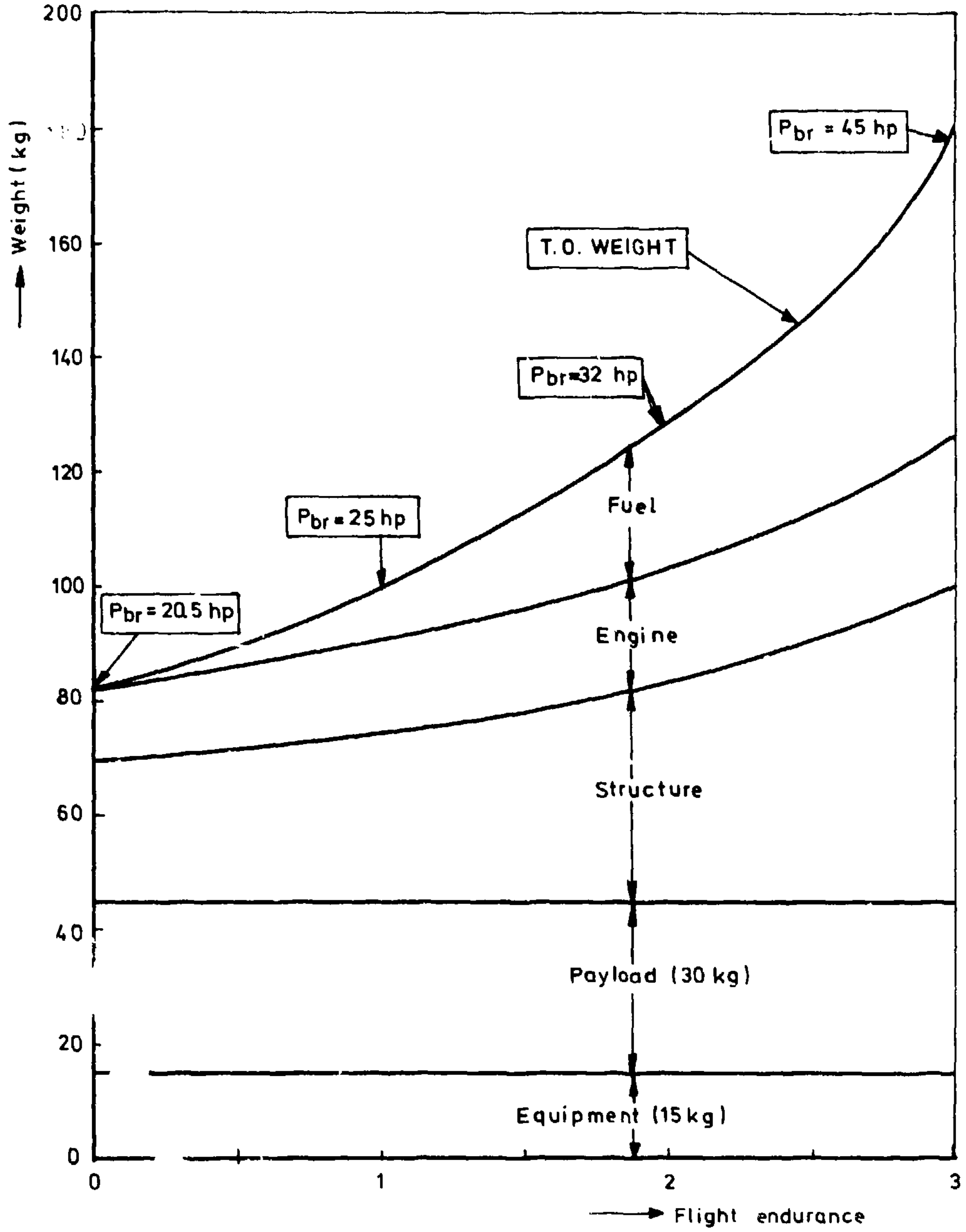


Fig.3.2 Vehicle weight vs. flight endurance for 30 kg payload; RPV-conventional configuration

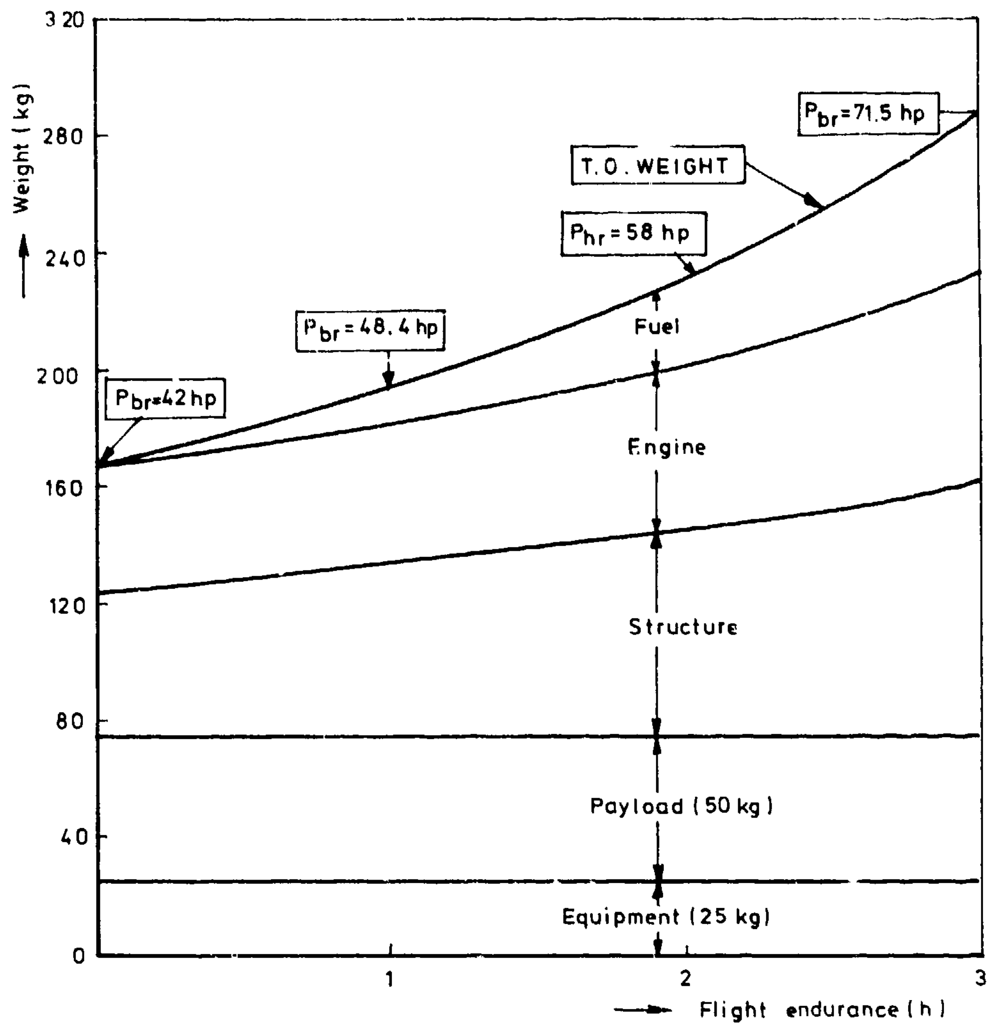


Fig.3.3 Vehicle weight vs. flight endurance for 50 kg payload; RPV-conventional configuration

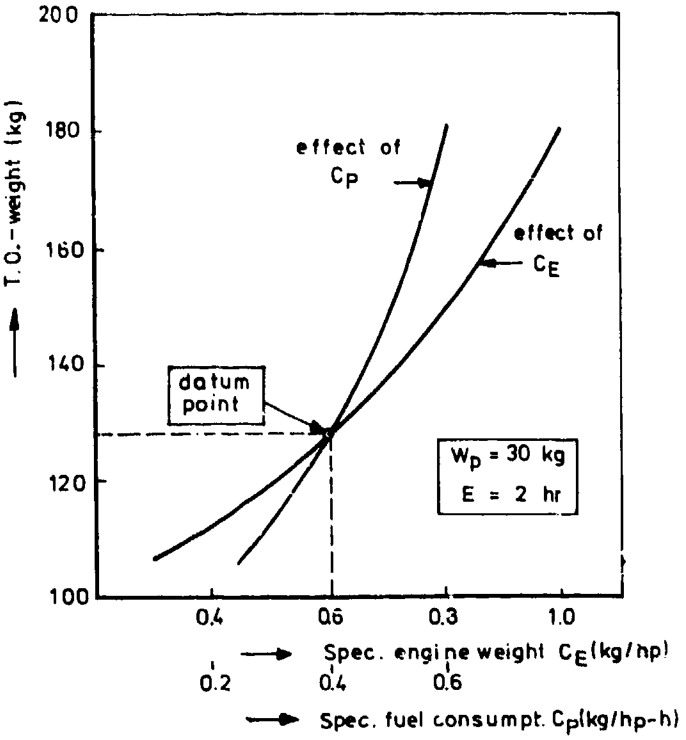


Fig.3.4 Effect of engine charau'ɛristics on take-off weight

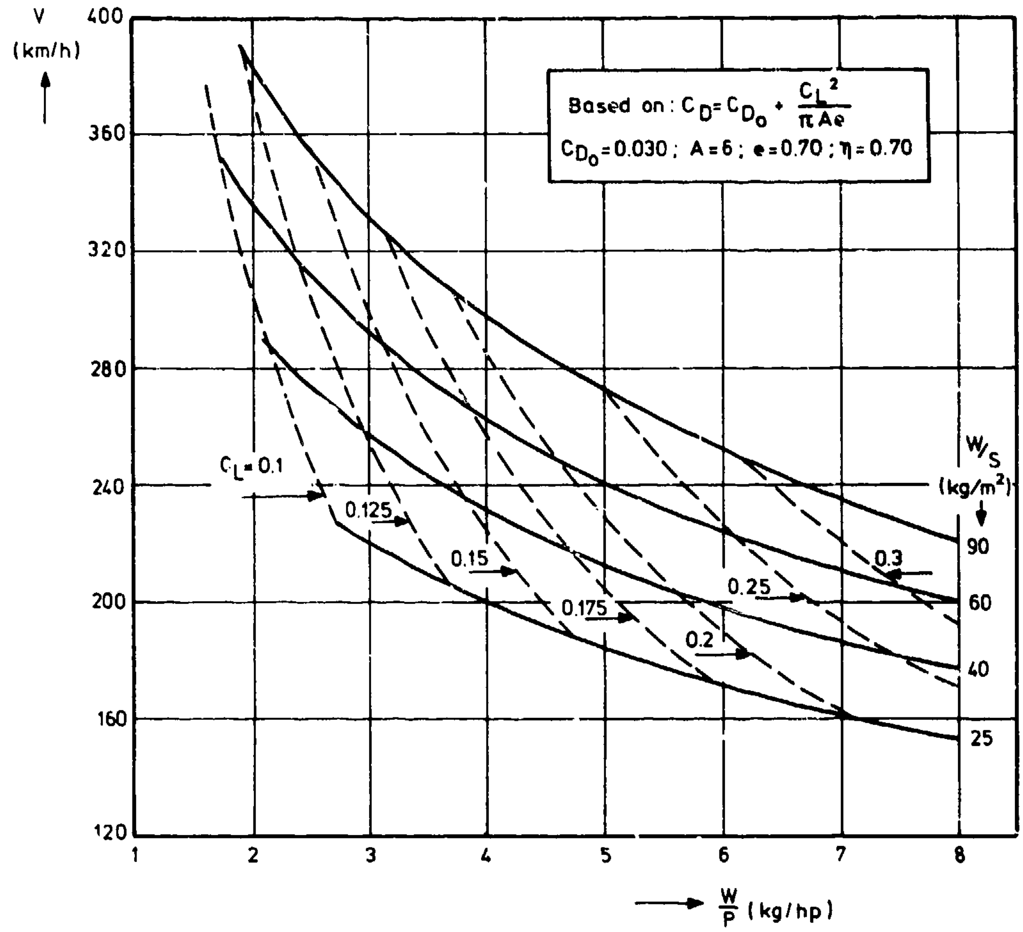


Fig.3.5 Cruise speed, wing- and power loading for steady level flight at sea-level (ISA)

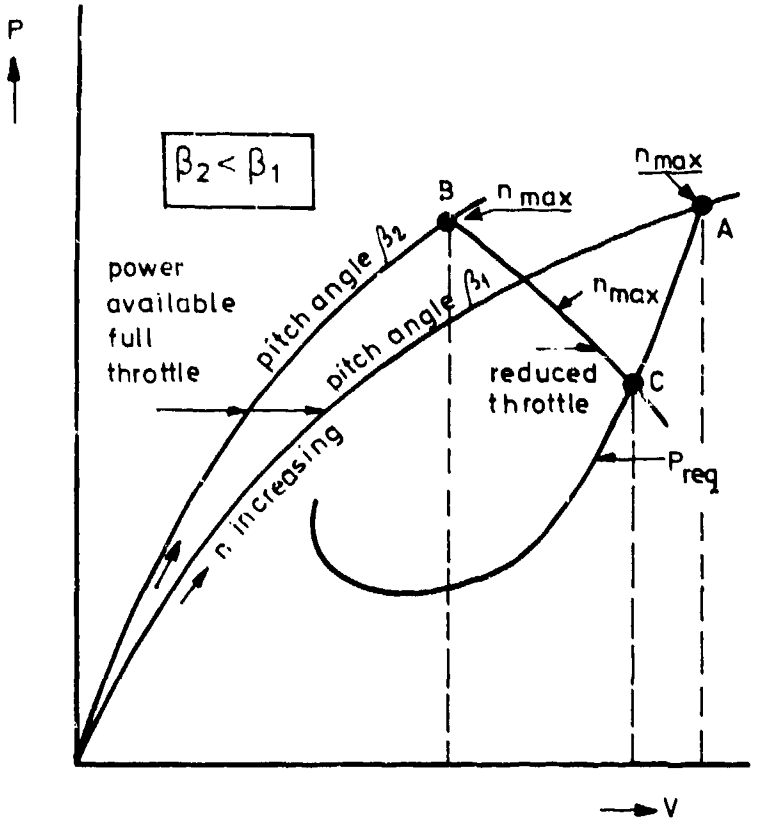


Fig.3 6 Power available for engine with fixed-pitch propeller and two different pitch-angles of the blades

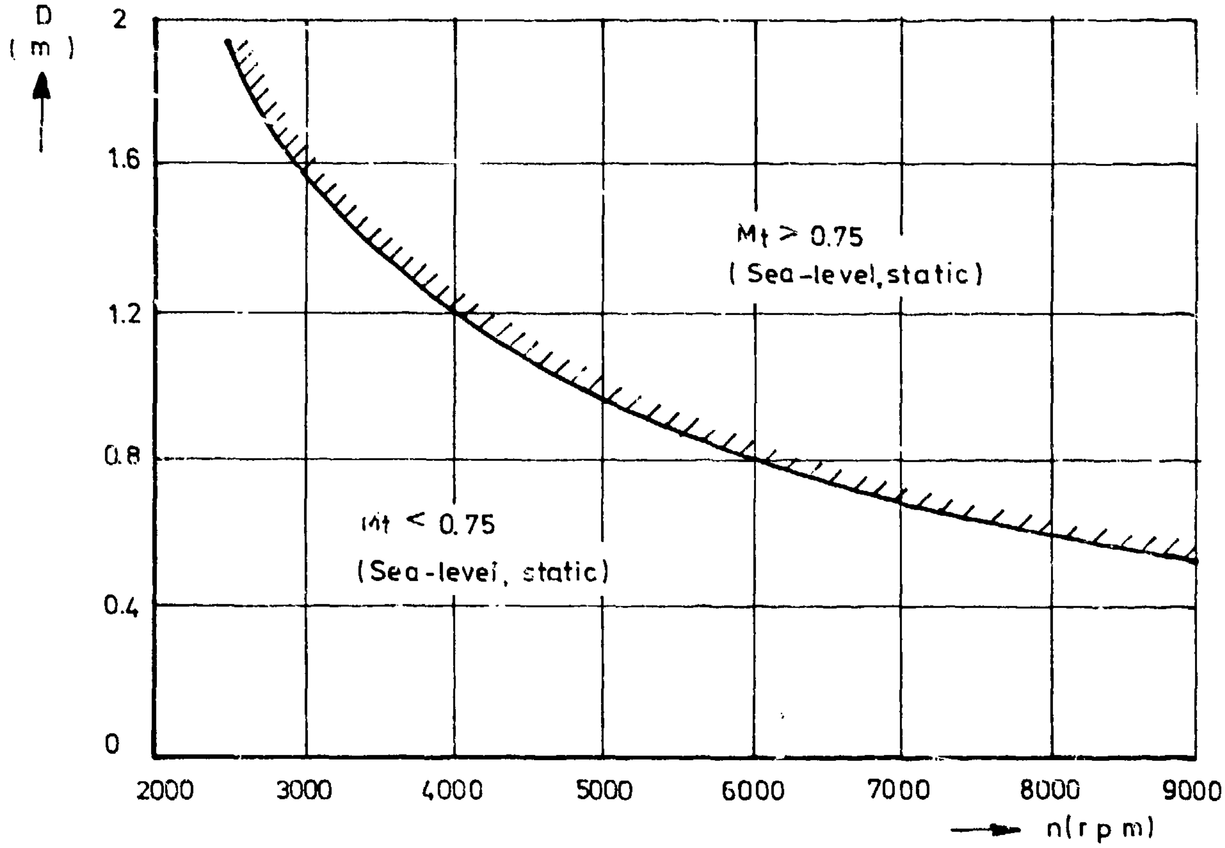


Fig.3.7 Propeller diameter vs. engine speed

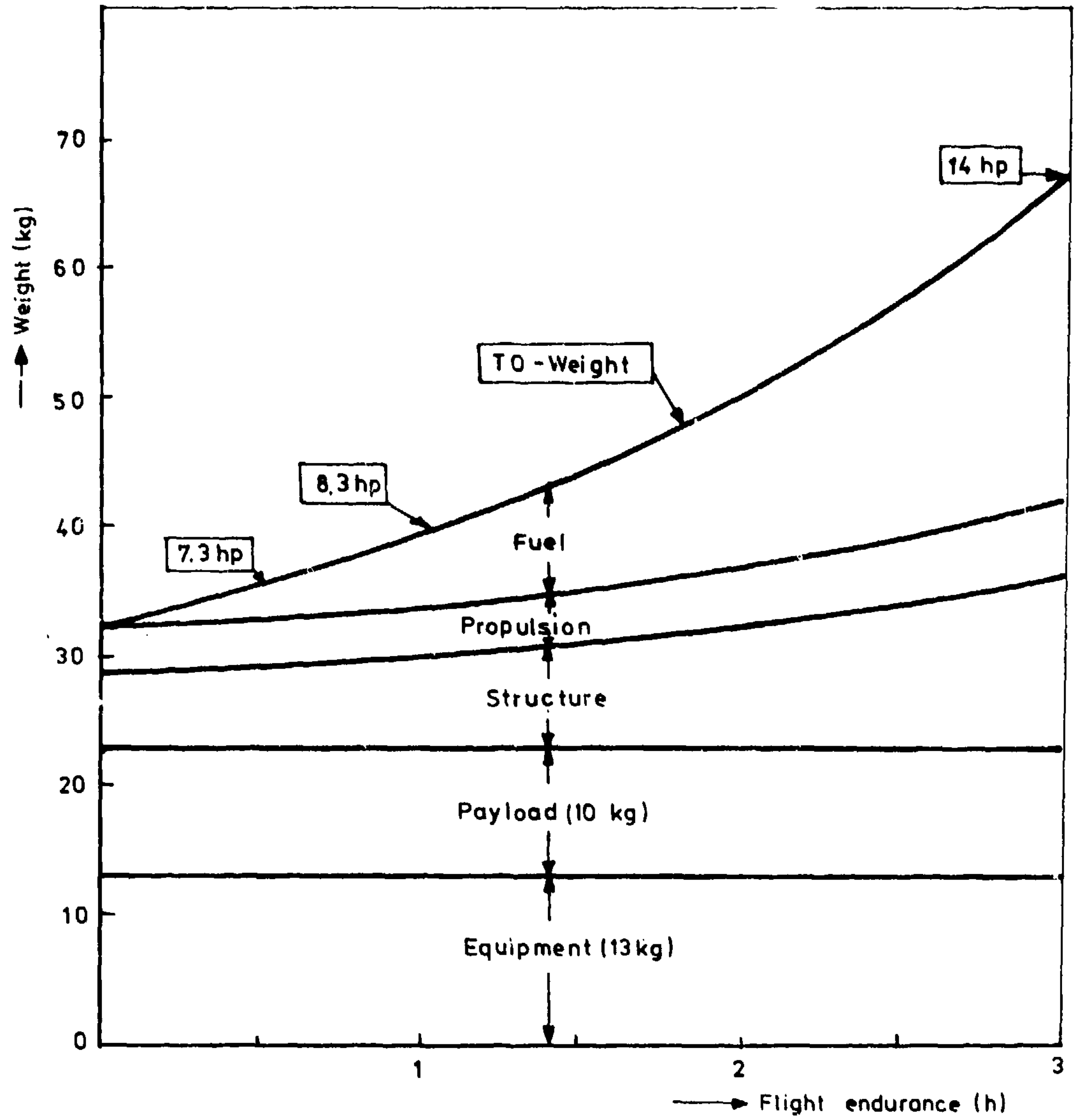


Fig.3.8 Vehicle weight vs. flight endurance for 10 kg payload, RPV-delta configuration

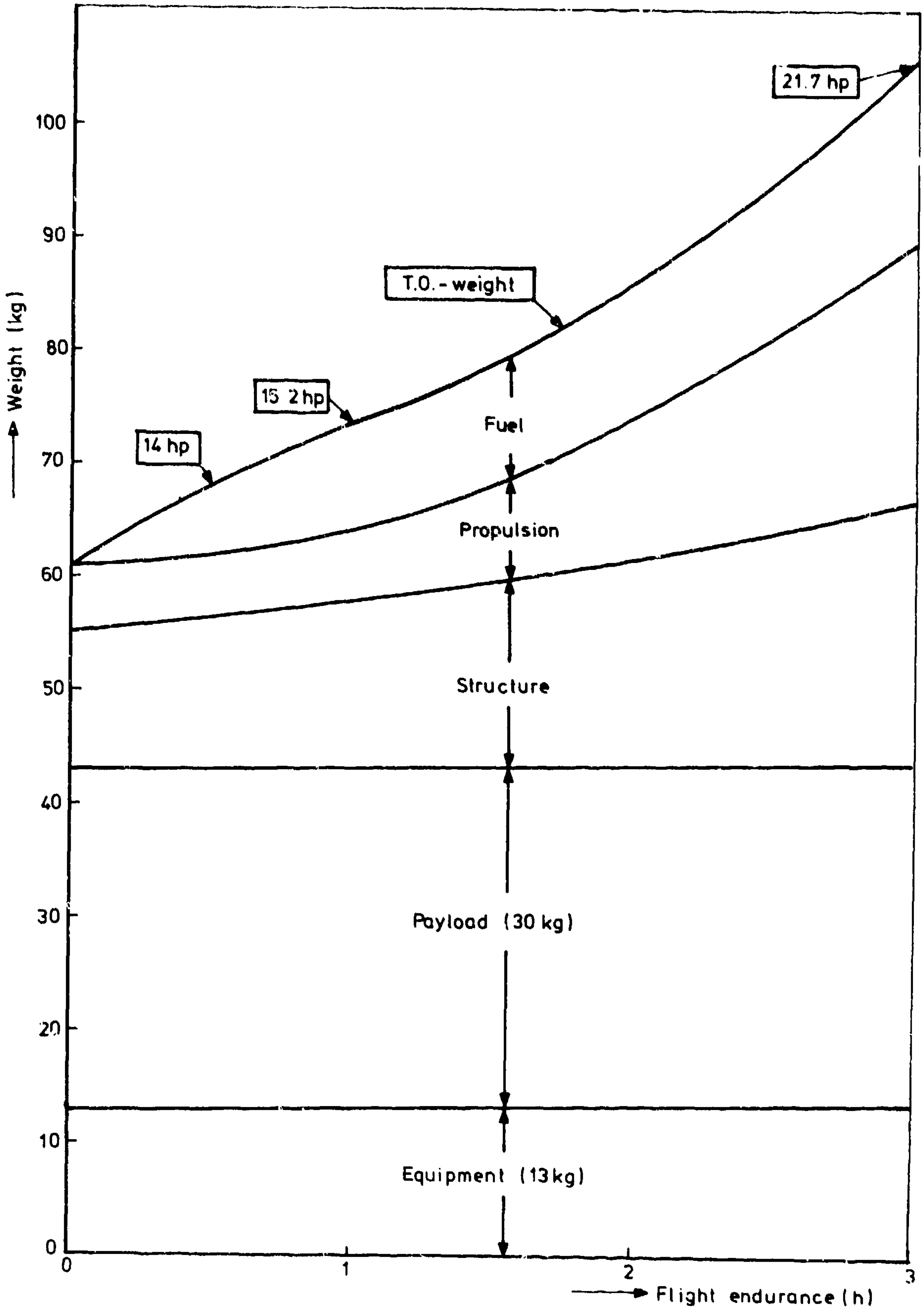


Fig.3.9 Vehicle weight vs. flight endurance for 30 kg payload, RPV-delta configuration

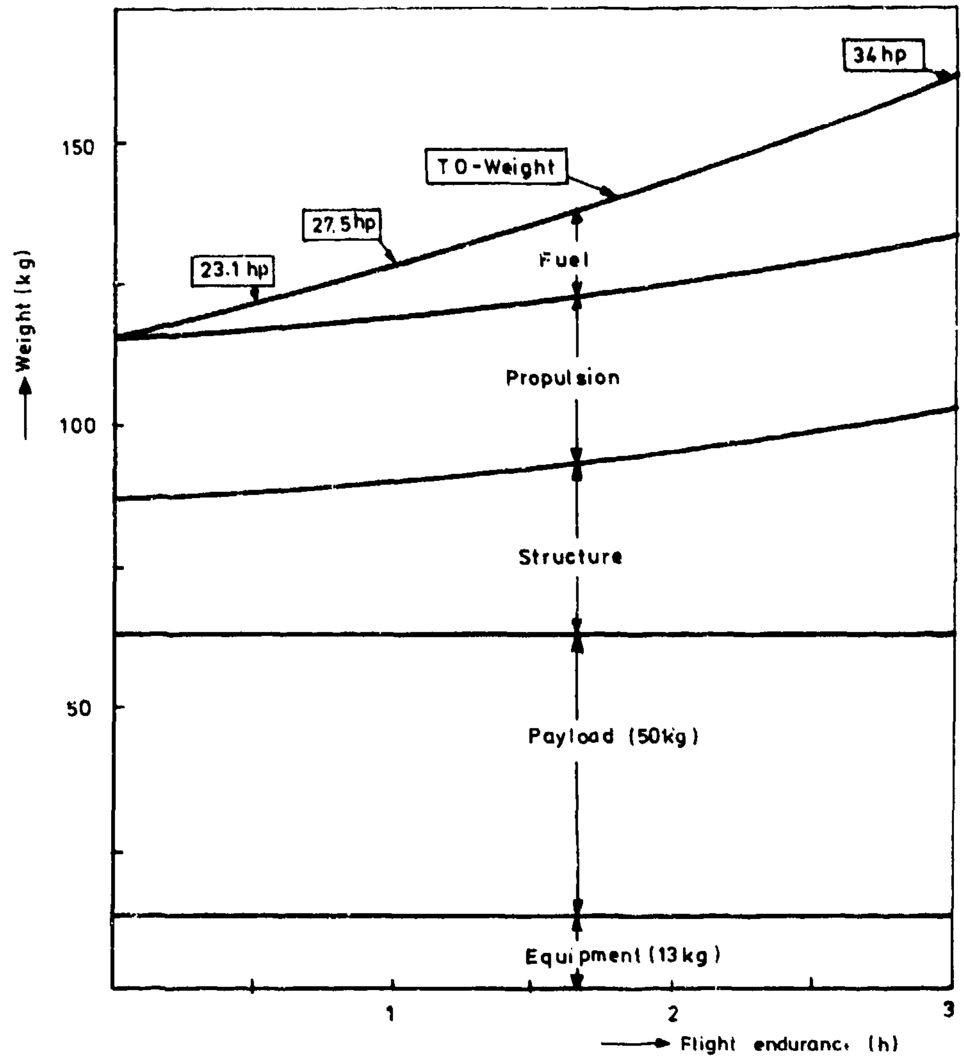


Fig.3.10 Vehicle-weight vs. flight endurance for 50 kg payload, RPV-delta configuration

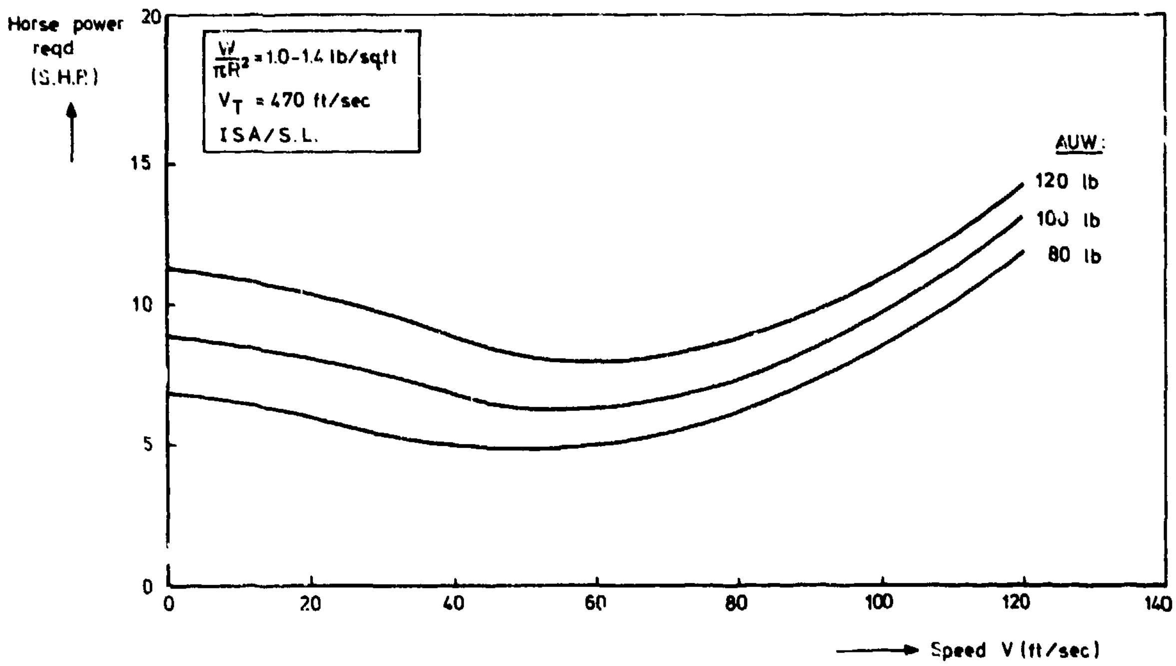


Fig.3.11 Power requirements for rotary-wing RPV; payload 10 kg

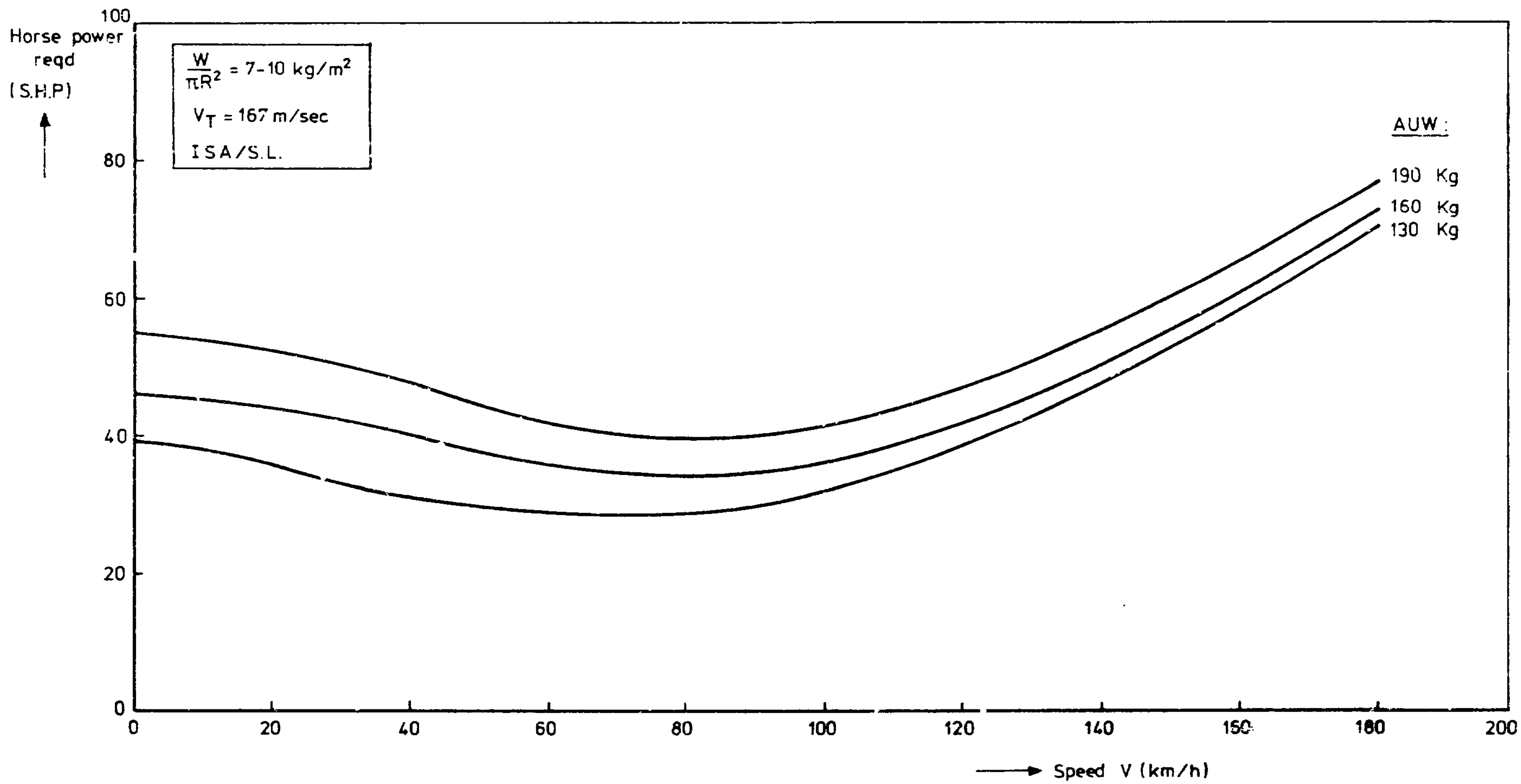


Fig.3.12 Power requirements for rotary-wing RPV; payload 30 kg

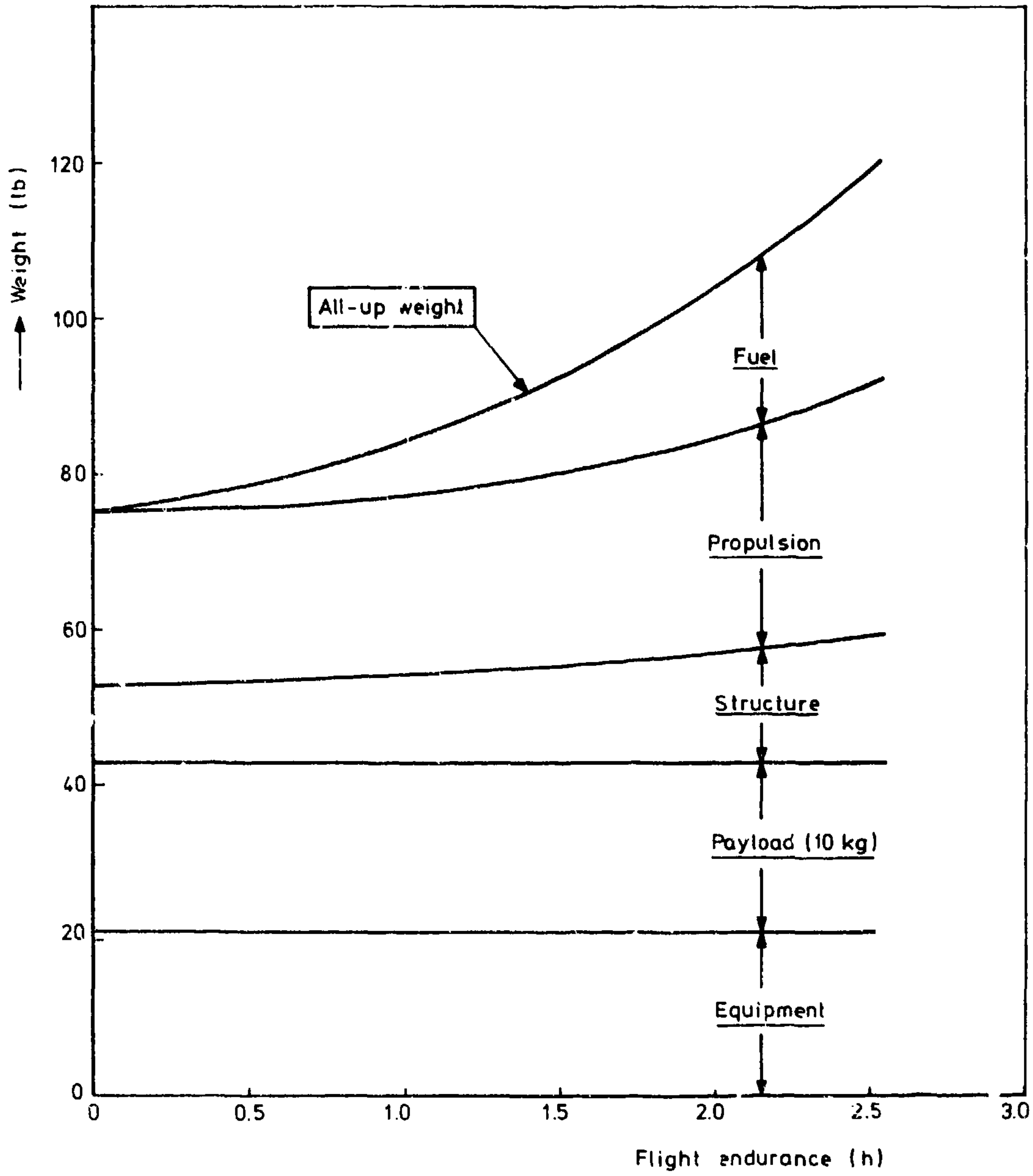


Fig.3.13 Vehicle weight vs. flight endurance for 10 kg payload; rotary-wing RPV

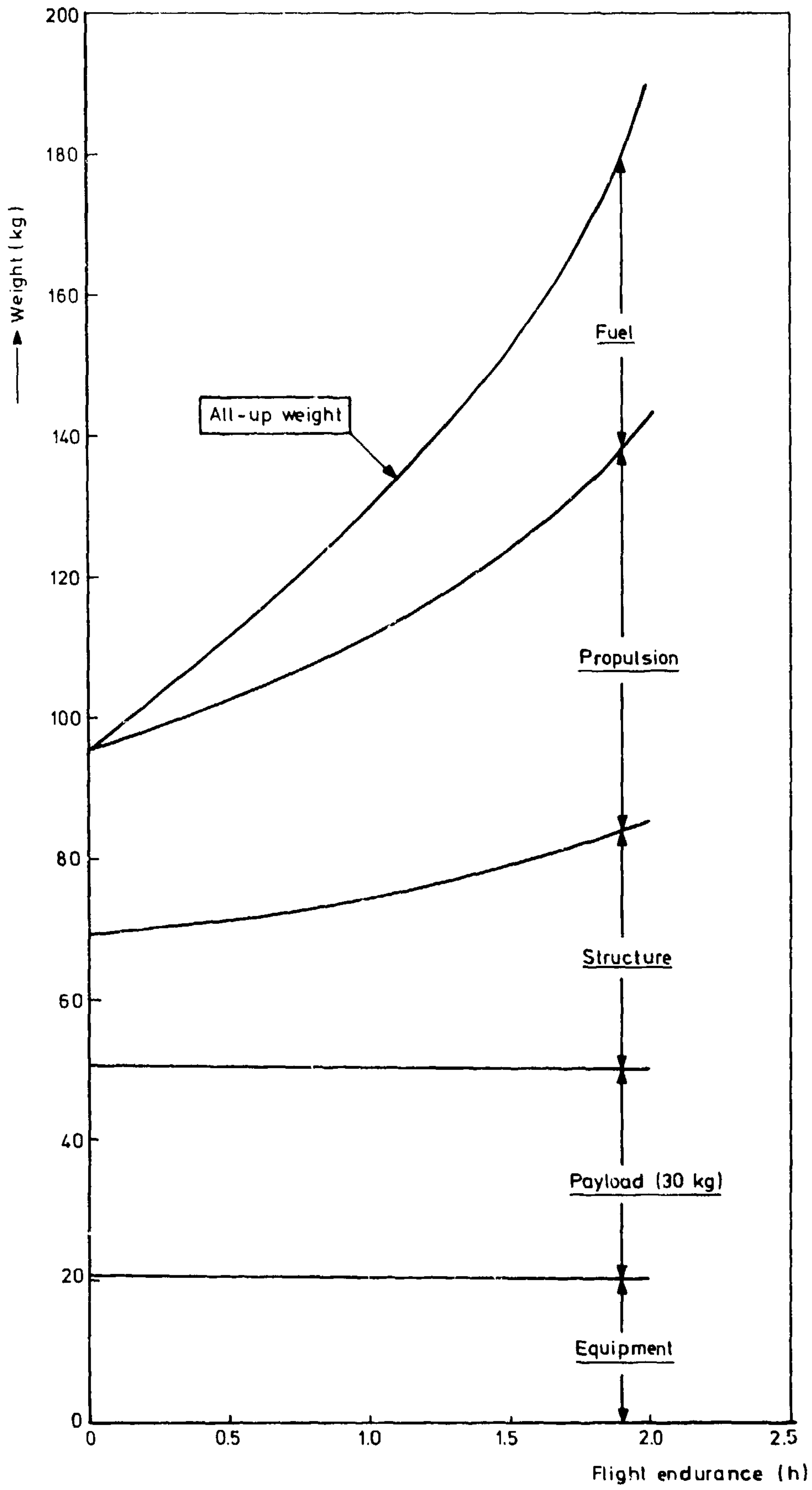


Fig.3.14 Vehicle-weight versus flight endurance for 30 kg payload; rotary-wing RPV

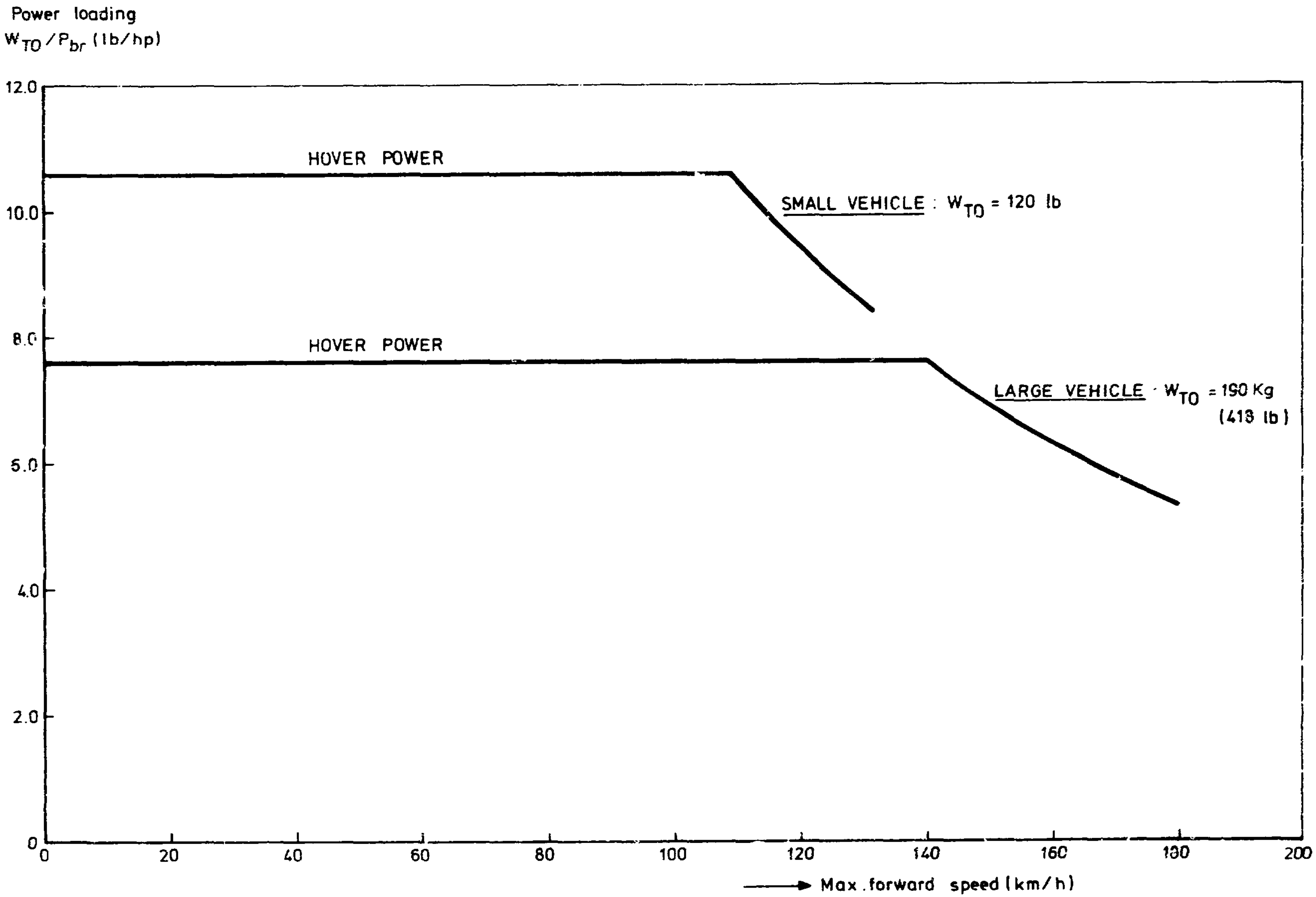
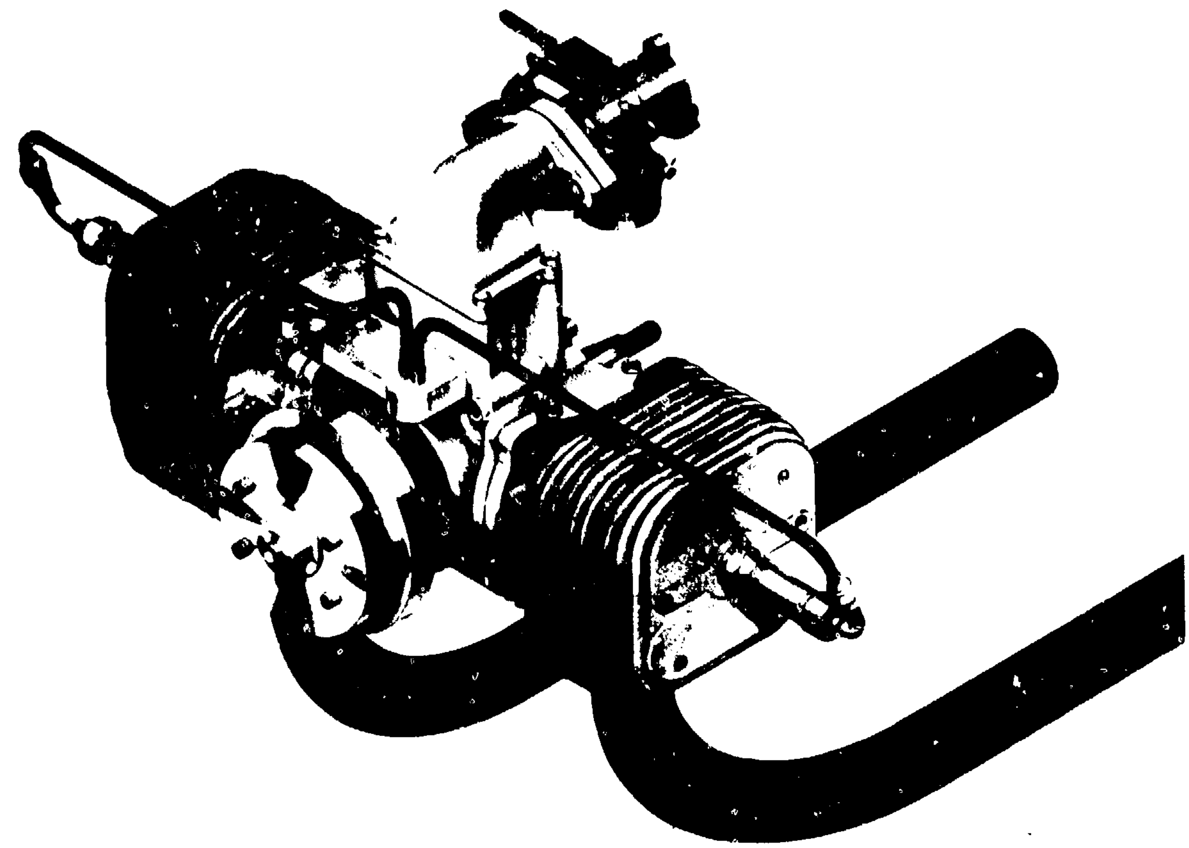


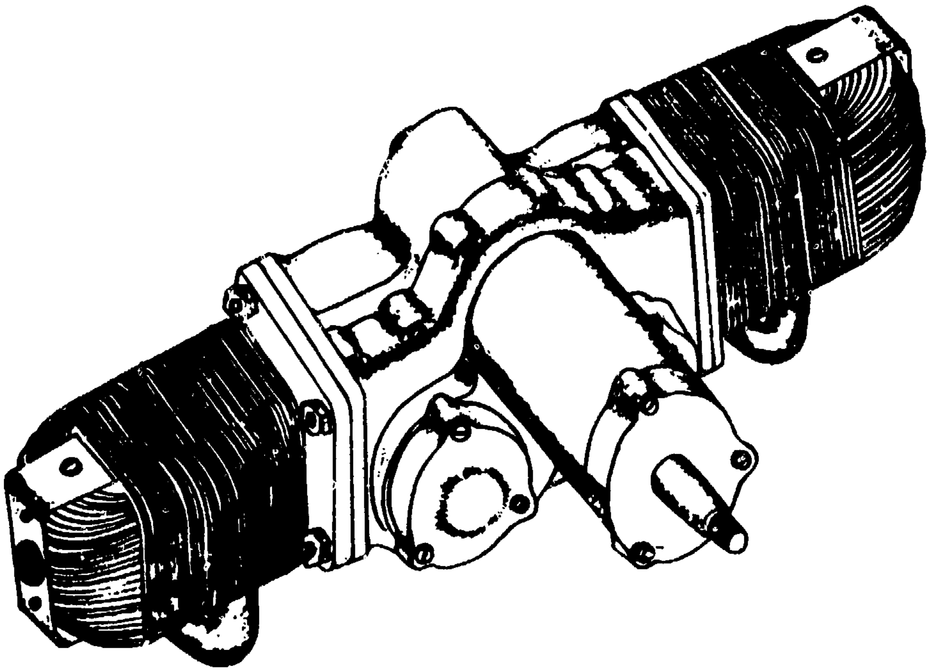
Fig.3.15 Power loading versus forward speed for rotary-wing RPV's



ENGINE CHARACTERISTICS

Displacement	16.7 cu. in.
Power	20 Horsepower
Power--Growth	25-27 Horsepower
Weight	21.53 lbs.
SFC	.8
Alt. Capability	More than 12,000 Feet
Dimensions	9.44"L x 16.43"W x 9.3"H
Gas/Oil Mixture Ratio	30 to 1
Expected Engine Life	More than 150 Hours
Induction System	Reed Valve
Engine Speed	7500 RPM

Fig.4.1 Continental 20 hp engine



ENGINE CHARACTERISTICS

Bore	2.5 in.
Stroke	1.625 in.
Displacement	16.0 cu. in.
Rated Power	20 hp
Engine Speed	7500 RPM
BSFC @ rated power	.8 lb/hp/hr
Weight	22.81 lbs
Length	12 in.
Width	18 in.
Height	6.5 in.

Fig.4.2 Aerotech 20 hp engine

APPENDIX 1

GROUP A OF PEP/WG 06

Members/Observers:

- Dipl-Ing. Georg Heise, Firma Dornier GmbH, Friedrichshafen/Bodensee, Germany.
- Mr Henry Morrow, US Army AMRD Laboratory, Fort Eustis, Virg., U.S.A.
- Mr Anthony Peduzzi, Procurement Executive, Min. of Defence, London, United Kingdom.
- Prof. Hans Wittenberg, Delft University of Technology, Delft, The Netherlands (Chairman).
- Mr Jean Fournet, Direction des Recherches et Moyens d'Essais SDR/G72, Paris-Armées, France (Observer).
- Mr Richard A.Rudey, NASA Lewis Research Centre, Cleveland, Ohio, U.S.A. (Observer).

Meetings:

January, 12 and 13, 1976
May , 17 and 18, 1976
July , 22 and 23, 1976
January, 10 and 11, 1977
April , 28 , 1977

All meetings were arranged in AGARD Headquarters in Paris (France), except the second meeting which took place in Porz-Wahn (W-Germany).

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APPENDIX 2

A SURVEY OF PISTON ENGINES, AVAILABLE & DEVELOPED IN THE POWER RANGE 10-100 BHP, SUITABLE FOR POWERING REMOTELY PILOTED VEHICLES

by

Weslake & Company Ltd.
Harbour Road
Rye Harbour
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March 1976

CONTENTS

I SUBJECT

A survey of piston engines, available and developed in the power range 10-100 BHP, suitable for powering remotely piloted vehicles.

This survey follows a previous task carried out for the British Ministry of Defence on engines in the power range 20-30 brake horse power and includes data collected for that report.

II OBJECT

The characteristics required of the engine are as follows:

A.	Maximum rated power	10-100 BHP
B.	Minimum power	
C.	Engine attitude	66% of rated position of output shaft vertically or horizontally
D.	Specific weight	Better than 2.0 lb/BHP
E.	Specific fuel consumption	Better than 1.5 lb/BHP/hr
F.	Engine and fuel weight to be a minimum for flight durations of 1-2 hours (mission "1")	
G.	Engine and fuel weight to be a minimum for flight durations of more than 2 hours (mission "2")	
H.	Altitude range (ISA plus 15°C)	"1" Sea Level to 2,000 m "2" Sea Level to 5,000 m
I.	Minimum starting temperature	−15°C
J.	Cooling	Air cooled
K.	Fuel	Av-gas–pump gasoline or alcohol fuel
L.	Desirable life	Minimum of 100 cycles of 1½ hours duration each
M.	Failure rate	Not more than 1% per cycle
N.	Other desirable characteristics	Minimum noise, minimum smoke, minimum vibration

III DISCUSSION

The survey has clearly shown the following salient features:-

1. The normal mass produced motor cycle engine, although capable of high specific performance cannot be considered for vehicles due to:

   - Manufacturers' disinclination to be involved, and difficulty of running engines when integral gearbox removed.
   - All major Japanese motor cycle manufacturers who were approached have refused to become involved (Honda, Yamaha, Kawasaki) except for Suzuki who stated that gearbox could not be removed.
   - The Weslake V twin 4 cycle engine with its consequential good specific performance could be considered if its unusual cylinder layout was acceptable.

2. The production air cooled industrial engine can be ruled out on a specific weight basis.

3. The production air cooled automobile engine in standard form can be ruled out on a specific weight basis.

4. In modified form, as used in many light aircraft, the air cooled automobile engine appears to be a possibility. Availability, low initial cost, and good specific fuel consumption could make the unit of interest, especially for the longer flight missions.

5. The high performance 2 cycle engine produced by many manufacturers for Kart racing, snowmobiles, and other forms of sport appear to be the best compromise of production engines for much of the power envelope.

6. The well known 4 cycle aero engines of proven design does appear to be of interest in the highest power category, and for the longer missions; price could be a problem. The certified 2 cycle aero engine must of course score on the specific weight analysis, and a number are listed.

7. At the low end of the power envelope the specially designed and built 2 cycle 2 cylinder glo fuel engine must be of interest, although its high specific fuel consumption does restrict its usefulness to short duration flights.

The engine documentation (Section VI of this appendix) shows the above mentioned classes have the following general characteristics:

Production 4 cycle automobile engines modified for aero use have a

Specific weight of approx.	2.6 lb/bhp
and Specific fuel consumption of	.55 lb/bhp/hr

Production 4 cycle aero engines have a

Specific weight of approx.	2.1 lb/bhp
and Specific fuel consumption of	.55 lb/bhp/hr

Production 2 cycle aero engines have a

Specific weight of approx.	0.85 lb/bhp
and Specific fuel consumption of	0.85 lb/bhp/hr

Production 2 cycle "sport" engines have

Specific weight of approx.	1.5 lb/bhp
Specific fuel consumption of	0.9 lb/bhp/hr
in Snowmobiles rising to	1.2 lb/bhp/hr

Production 2 cycle mini RPV glo engines

Specific weight of approx.	0.6 lb/bhp
Specific fuel consumption of	1.8 lb/bhp/hr

The total engine and fuel weight (Mlb) for a given flight time at rated power is given by the equation

$$M = P\ (\text{Sp. Wt. eng} + \text{S.F.C.} \times t)$$

when P is Rated bhp
Specific weight of engine is in lb/bhp
Specific fuel consumption is in lb/bhp/hr
t is flight time in hours

Substituting the previously stated general figures in the above equation immediately shows which type of engine would be preferred for any given mission time, provided such an engine is available in the power category required.

This survey assumes that all fuels are readily available and no engine has been excluded on this ground. Range covered includes:

Avgas 100/130, Avgas 100L
Premium Roadside Pump 98 RON
Standard Roadside Pump 90 RON
Alcohol based glo-fuel

No engine manufacturer considered starting at −15°C a problem. Aero engines, automobile engines, and particularly snowmobile engines are well used to much lower temperatures.

No manufacturer, other than those of conventional aero engines, have offered specific data on power loss at altitude.

Information obtained from Lockheed Missiles and Space Company Inc. suggest that the power loss at altitude is greater than the classic ratio given by

$$\frac{\text{Altitude Pressure}}{\text{Sea Level Pressure}} \times \left(\frac{\text{Sea Level Temperature}}{\text{Altitude Temperature}}\right)^{0.5}$$

They suggest that a more correct assumption for the small 2 cycle engine with particular reference to the McCulloch 101 is given by:-

Altitude Power $=$ S.L. Power $\times$ $[(1 + \alpha)\,\sigma - \alpha]$

When σ $=$ Altitude density/Sea level density

α $=$ 0.25 to 0.35*

* Editor's note: This value of α is much higher than the value which is considered as "standard" for higher powered aero-engines (C = 0.132).

IV CONCLUSION

A study of the required parameters shows that in the horse power range up to 60 BHP the requirements will be most likely met by a two cycle engine which has been developed for competitive sport.

Above 60 BHP there is a possibility that a well developed 4 cycle engine (with its considerably lower specific fuel consumption) could be advantageous, particularly for the longer mission. In this area developed aero engines and automobile engines could be considered.

An ideal engine, or range of engines, to meet the RPV requirement does not exist.

Attention must be drawn to the range of 2 cycle free air cooled engines manufactured by Kohler of Canada Limited, model numbers K440-2RS and K340-2RS. These would appear to have a specific weight as low as the purpose built 2 cycle aero engine and yet having only, even in the larger size, a cubic capacity of 436 cc. These engines have, of course, been developed for racing and are not the everyday production item.

V LIST OF POSSIBLE ENGINE MANUFACTURERS

Automobile Citroen SA	117-167 Quai Andre Citroen 75747 Paris, France
Avco Lycoming Engine Group	Williamsport PA, 17701, USA
Avions Roger Drure Ardem	20 Avenue de General Clavey Paris 16, France
BMW Motorad GmbH	Munich, West Germany
Cicare Aeronautica	CC 24 Saladillo Provincia de Buenos Aires Argentine
Clinton Engine Corp.	Maquoketa Iowa, 52060, USA
Cuyuna Engine – Scorpion Inc.	Crosby, Minnesota, USA
D.H.Enterprises	4909 W.Compton Blvd Lawndale CA, 90260, USA
Fichtel & Sachs AG	8720 Schweinfurt West Germany
Franklin Engine Co. Inc.	Syracuse New York, USA
Hirth Motoren KG	7141 Benningen/Neckar Kreis Ludwigsburg West Germany
Kohler of Canada Ltd.	6390 Northwest Drive Mississauga, Ontario Canada
Kolbo Korp	9902 W.Broadway Anaheim, CA, 92804, USA
Limbach Motorenbau	D-533 Konigs Winter 21 Sassenberg West Germany

Lloyd Motoren Werke	D 28 Bremen 1 Duckwitzstrasse 51-59 West Germany
McCulloch Corp.	PO Box 92180 Los Angeles, CA, 90009, USA
Meteor SpA	146 Via Nomentana 00162 Roma, Italy
Motosacoche SA (MAG)	Route des Acadias 56 1211 Geneve 26 Switzerland
Northrop Corp.	Ventura Div., 1515 Rancho Conejo Boulevard Newbury Park, CA, 91320, USA
Nelson Aircraft Corp.	PO Box 454 Irwin, PA, 15642, USA
Pieper-Stark Motorenbau GmbH	Minden/Westf West Germany
Porsche AG	Stuttgart West Germany
Rectimo Savoie Aviation	Aerodrome de Chambery 73 Savoie, France
Rollason Aircraft & Engines Ltd.	Shoreham by Sea Sussex, England
Rolls Royce Motors Limited	Crewe, Cheshire England
Teledyne Continental	PO Box 90 Mobile Alabama, 36601, USA
Volkswagen AG	Wolfsburg West Germany
Weslake & Company Limited	Rye East Sussex England

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VI DATA ON POSSIBLE ENGINES, LISTED IN DESCENDING POWER

RPV ENGINE SEARCH (AGARD) HP GROUP 130

Country of origin:	West Germany
Manufacturer:	Porsche AG Stuttgart
Type designation:	
Rated b.h.p. @ r.p.m.:	130 bhp @ 5,600 r.p.m.
Number of cylinders and layout:	6 cylinder opposed
Combustion cycle and fuel:	4 cycle pump fuel
Bore x stroke mm.:	84 x 70.4
Cubic capacity cc.:	2341 cc
Normal operating position:	Horizontal
Weight:	
Specific weight:	
Specific fuel consumption at rating:	
Estimated fuel weight for 1 hour, at rated power:	
Total engine+fuel weight for 1 hour:	
Specific weight for 1 hour flight:	
Total engine+fuel weight for 2 hours:	
Specific weight for 2 hour flight:	
Estimated engine life:	
Original engine use and users:	Porsche 911T automobile
Comments:	Porsche AG did not release details of engines used in car.

Country of origin:	USA
Manufacturer:	Avco Lycoming Engine Group Williamsport, PA 17701
Type designation:	O-235-L2C
Rated b.h.p. @ r.p.m.:	118 @ 2800 r.p.m.T.O.
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	4 cycle avgas 100/130
Bore x stroke mm.:	111.1 x 98.4
Cubic capacity cc.:	3823.0
Normal operating position:	
Weight:	248 lb
Specific weight:	2.10 lb/bhp
Specific fuel consumption at rating:	.52 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	60.8 lbs
Total engine+fuel weight for 1 hour:	308.8 lbs
Specific weight for 1 hour flight:	2.62 lb/bhp
Total engine fuel+weight for 2 hours:	369.6 lb
Specific weight for 2 hour flight:	3.13 lb/bhp
Estimated engine life:	In excess of 1000 hours could be expected at a rating of 112 bhp @ 2600 r.p.m.
Original engine use and users:	Multitudinous light aircraft
Comments:	Lycoming state that a vertical version of this engine could be built readily, using existing conversion components from larger engine. Direct drive propeller.

RPV ENGINE SEARCH (AGARD) HP GROUP 110

Country of origin:	Italy
Manufacturer:	Meteor SpA 146 Via Nomentana 00162 Roma
Type designation:	Alfa 2V
Rated b.h.p. @ r.p.m.:	110 @ 2800, constant 8000 ft
Number of cylinders and layout:	4 cylinder radial
Combustion cycle and fuel:	2 cycle supercharged
Bore x stroke mm.:	
Cubic capacity cc.:	
Normal operating position:	Vertical (horizontal version)
Weight:	130 lb
Specific weight:	1.18 lb / bhp
Specific fuel consumption at rating:	0.48 lb/bhp-hr (claim*)
Estimated fuel weight for 1 hour, at rated power:	52 lb
Total engine+fuel weight for 1 hour:	182 lb
Specific weight for 1 hour flight:	1.65 lb/bhp
Total engine+fuel weight for 2 hours:	234 lb
Specific weight for 2 hour flight:	2.13 lb/bhp
Estimated engine life:	Sufficient for target drones
Original engine use and users:	Meteor PI Target Drones and Meteor PIR Reconnaissance Drone Italian Government
Comments:	

* This figure remarkably low for two cycle engine.

RPV ENGINE SEARCH (AGARD) HP GROUP 100

Country of origin:	UK / USA
Manufacturer:	Rolls Royce Motors Ltd Crewe, England
Type designation:	Rolls Royce Continental 0-200-A
Rated b.h.p. @ r.p.m.:	100 bhp @ 2750 r.p.m.
Number of cylinders and layout:	4 cylinders opposed
Combustion cycle and fuel:	4 cycle
Bore x stroke mm.:	103.2 x 98.4
Cubic capacity cc.:	3292.3
Normal operating position:	Horizontal
Weight:	189.7/220. lb, without/with accessories
Specific weight:	2.5 lb / bhp
Specific fuel consumption at rating:	0.553 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	55.3
Total engine+fuel weight for 1 hour:	305.3 lb
Specific weight for 1 hour flight:	3.05 lb/bhp
Total engine+fuel weight for 2 hours:	360.6 lb
Specific weight for 2 hour flight:	3.61 lb/bhp
Estimated engine life:	In excess of 1000 hours could be expected
Original engine use and users:	Light aircraft Many
Comments:	Manufactured under licence in UK

RPV ENGINE SEARCH (AGARD) HP GROUP 100

Country of origin:	UK
Manufacturer:	Weslake & Co. Ltd Harbour Road, Rye, East Sussex
Type designation:	V - 1000
Rated b.h.p. @ r.p.m.:	100 bhp at 6,500
Number of cylinders and layout:	Twin 55^{o} V
Combustion cycle and fuel:	4 cycle Avgas 100/130
Bore x stroke mm.:	88.6 x 85.8
Cubic capacity cc.:	990
Normal operating position:	Horizontal
Weight:	Estimated at 90 lb
Specific weight:	0.9 lb / bhp
Specific fuel consumption at rating:	0.6 ib/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	60 lb
Total engine+fuel weight for 1 hour:	150 lb
Specific weight for 1 hour flight:	1.5 lb/bhp
Total engine+fuel weight for 2 hours:	210 lb
Specific weight for 2 hour flight:	2.1 lb/bhp
Estimated engine life:	
Original engine use and users:	Motor cycle racing
Comments:	Small batch production during 1976. Engine based on single cylinder unit which has been in production for over one year.

Country of origin:	USA
Manufacturer:	Teledyne Continental PO Box 90, Mobile Alabama 36601
Type designation:	C 90
Rated b.h.p. @ r.p.m.:	95 bhp @ 2625
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	4 cycle Avgas 80/87
Bore x stroke mm.:	103.2 x 98.4
Cubic capacity cc.:	3280
Normal operating position:	Horizontal
Weight:	186 lb
Specific weight:	1.96 lb/bhp
Specific fuel consumption at rating:	estimated 0.6 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	57 lb
Total engine+fuel weight for 1 hour:	243 lb
Specific weight for 1 hour flight:	2.56 lb/bhp
Total engine+fuel weight for 2 hours:	300 lb
Specific weight for 2 hour flight:	3.16 lb/bhp
Estimated engine life:	
Original engine use and users:	Light aircraft

Comments:

RPV ENGINE SEARCH (AGARD) HP GROUP 90

Country of origin:	USA
Manufacturer:	Northrop Corp. Ventura Div. 1515 Rancho Conejo Blvd Newbury Park CA 91320
Type designation:	4318F/O - 100 - 3
Rated b.h.p. @ r.p.m.:	90 bhp @ 4,100 rpm
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	2 cycle Avgas 100/130
Bore x stroke mm.:	80.96 x 79.37
Cubic capacity :	1635
Normal operating position:	Horizontal (vert. in gyrocopter)
Weight:	77 lb
Specific weight:	0.85 lb/bhp
Specific fuel consumption at rating:	0.85 lb/bhp/hr
Estimated fuel weight for 1 hour, at rated power:	76.5 lb
Total engine+fuel weight for 1 hour:	153.5 lb
Specific weight for 1 hour flight:	1.70
Total engine+fuel weight for 2 hours:	230 lb
Specific weight for 2 hour flight:	2.55 lb / bhp
Estimated engine life:	Good reports
Original engine use and users:	Northrop Shelduck Target Drones etc. US Government
Comments:	UK Contact: Aerial Targets Ltd 3 Hobart Place, London SW1 01.235 1304 Telex

RPV ENGINE SEARCH (AGARD) HP GROUP 85

Country of origin:	West Germany
Manufacturer:	Limbach Motoren Bau D 5[illegible]3 Konigs Winter 21 Sassenberg
Type designation:	SL 2400 ED
Rated b.h.p. @ r.p.m.:	85 @ 3,600
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	4 cycle
Bore x stroke mm.:	103 x 77
Cubic capacity cc.:	2368
Normal operating position:	
Weight:	187 lb
Specific weight:	2.2 lb / bhp
Specific fuel consumption at rating:	
Estimated fuel weight for 1 hour, at rated power:	
Total engine+fuel weight for 1 hour:	
Specific weight for 1 hour flight:	
Total engine+fuel weight for 2 hours:	
Specific weight for 2 hour flight:	
Estimated engine life:	
Original engine use and users:	For ultra-light aircraft and powered sailplanes
Comments:	

RPV ENGINE SEARCH (AGARD)	HP GROUP 76
Country of origin:	Canada
Manufacturer:	Kohler of Canada Ltd 6390 Northwest Drive Mississauga, Ontario
Type designation:	K440-2RS
Rated b.h.p. @ r.p.m.:	76 @ 8,500 would be typical
Number of cylinders and layout:	2 cylinders in line
Combustion cycle and fuel:	2 cycle Premium pump
Bore x stroke mm.:	68 x 60
Cubic capacity cc.:	436
Normal operating position:	Horizontal or vertical
Weight:	64 lb
Specific weight:	0.84 lb/bhp
Specific fuel consumption at rating:	Estimated at 1.0 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	76 lb
Total engine+fuel weight for 1 hour:	140 lb
Specific weight for 1 hour flight:	1.84 lb/bhp
Total engine+fuel weight for 2 hours:	216 lb
Specific weight for 2 hour flight:	2.84 lb/bhp
Estimated engine life:	Manufacturers confident of meeting requirement
Original engine use and users:	Racing snowmobiles
Comments:	The most highly developed engine in the air cooled Kohler range. In short run batch production. Probably the most suitable engine available in this power range. Other ratings could be derived. Weight includes 150 watt alternator

RPV ENGINE SEARCH (AGARD) HP GROUP 72

Country of origin:	West Germany
Manufacturer:	Limbach Motoren Bau D 533 Konigs Winter 21 Sassenberg
Type designation:	SL 1700 EB
Rated b.h.p. @ r.p.m.:	72 bhp @ 3,600
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	4 cycle
Bore x stroke mm.:	88 x 74
Cubic capacity cc.:	1800
Normal operating position:	Horizontal
Weight:	164 lb
Specific weight:	2.28 lb/bhp
Specific fuel consumption at rating:	
Estimated fuel weight for 1 hour, at rated power:	
Total engine+fuel weight for 1 hour:	
Specific weight for 1 hour flight:	
Total engine+fuel weight for 2 hours:	
Specific weight for 2 hour flight:	
Estimated engine life:	
Original engine use and users:	For ultra-light aircraft and powered sailplanes
Comments:	Twin carburettors

RPV ENGINE SEARCH (AGARD) HP GROUP 69

Country of origin:	Argentine
Manufacturer:	Cicare Aeronautica CC 24 Saladillo Provincia de Buenos Aires
Type designation:	4C2T
Rated b.h.p. @ r.p.m.:	69 bhp @ 4,500 r.p.m.
Number of cylinders and layout:	4 cylinders opposed
Combustion cycle and fuel:	2 cycle
Bore x stroke mm.:	74 x 76
Cubic capacity cc.:	1314
Normal operating position:	
Weight:	150 lb (incl. accessories and gearbox)
Specific weight:	2.17 lb / bhp
Specific fuel consumption at rating:	0.66 lb / bhp/ hr
Estimated fuel weight for 1 hour, at rated power:	45.5 lb
Total engine+fuel weight for 1 hour:	195.5
Specific weight for 1 hour flight:	2.83 lb/bhp
Total engine+fuel weight for 2 hours:	241 lb
Specific weight for 2 hour flight:	3.49 lb/bhp
Estimated engine life:	Assume normal aircraft standards
Original engine use and users:	Light aircraft
Comments:	Information from "Janes"

RPV ENGINE SEARCH (AGARD) HP GROUP 67

Country of origin:	West Germany
Manufacturer:	BMW Motorad GmbH Munich
Type designation:	
Rated b.h.p. @ r.p.m.:	67 bhp @ 7,000 rpm
Number of cylinders and layout:	2 cylinder opposed
Combustion cycle and fuel:	4 cycle pump fuel
Bore x stroke mm.:	90 x 70.6
Cubic capacity cc.:	898
Normal operating position:	Horizontal
Weight:	Estimated 100 lb
Specific weight:	1.5 lb/bhp
Specific fuel consumption at rating:	Estimated at 0.6 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	40 lb
Total engine+fuel weight for 1 hour:	140 lb
Specific weight for 1 hour flight:	2.09 lb/bhp
Total engine+fuel weight for 2 hours:	180 lb
Specific weight for 2 hour flight:	2.69 lb/bhp
Estimated engine life:	Would be expected to meet requirement
Original engine use and users:	BMW R 90S motor cycles
Comments:	Renowned in motor cycle field for smooth running and long life.

RPV ENGINE SEARCH (AGARD) HP GROUP 66

Country of origin:	West Germany
Manufacturer:	Volkswagen AG Wolfsburg
Type designation:	127
Rated b.h.p. @ r.p.m.:	66 bhp @ 4,000 rpm
Number of cylinders and layout:	4 cylinders opposed
Combustion cycle and fuel:	4 cycle pump fuel
Bore x stroke mm.:	93 x 66
Cubic capacity cc.:	1795
Normal operating position:	Horizontal
Weight:	273 lb in auto (est. 180 lb in aero)
Specific weight:	4.13 lb/bhp (2.72 lb/bhp)
Specific fuel consumption at rating:	0 56 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	36.96 lb
Total engine+fuel weight for 1 hour:	217 lb
Specific weight for 1 hour flight:	3.28 lb/bhp
Total engine+fuel weight for 2 hours:	254 lb
Specific weight for 2 hour flight:	3.48 lb/bhp

Estimated engine life:

Original engine use and users: Volkswagen cars

Comments:

RPV ENGINE SEARCH (AGARD) HP GROUP 60

Country of origin:	France
Manufacturer:	Citroen SA 117/167 Quia Andre Citroen 75747 Paris
Type designation:	G 12
Rated b.h.p. @ r.p.m.:	60 bhp @ 5750 rpm
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	4 cycle pump fuel 95 RON
Bore x stroke mm.:	77 x 65.6
Cubic capacity cc.:	1220
Normal operating position:	Horizontal
Weight:	226 lb in auto (est. 160 in aero)
Specific weight:	3.76 lb/bhp auto (2.66 aero)
Specific fuel consumption at rating:	0.56 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	33.6 lb
Total engine+fuel weight for 1 hour:	193.6 lb
Specific weight for 1 hour flight:	3.23 lb/bhp
Total engine+fuel weight for 2 hours:	227.2 lb
Specific weight for 2 hour flight:	3.79 lb/bhp
Estimated engine life:	Good in air, unknown in RPVs
Original engine use and users:	Citroen GS car

Comments:

RPV ENGINE SEARCH (AGARD) HP GROUP 60

Country of origin:	USA
Manufacturer:	Franklin Engine Co. Inc. Syracuse, New York
Type designation:	2A-120-CD
Rated b.h.p. @ r.p.m.:	60 bhp @ [illegible],200 rpm
Number of cylinders and layout:	2 cylinder opposed
Combustion cycle and fuel:	4 cycle Avgas
Bore x stroke mm.:	
Cubic capacity cc.:	1966.4
Normal operating position:	Horizontal
Weight:	133 lb
Specific weight:	2.2 lb/bhp
Specific fuel consumption at rating:	0.5 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	30 lb
Total engine+fuel weight for 1 hour:	163 lb
Specific weight for 1 hour flight:	2.72 lb/bhp
Total engine+fuel weight for 2 hours:	193 lb
Specific weight for 2 hour flight:	3.22 lb/bhp
Estimated engine life:	
Original engine use and users:	Light aircraft

Comments:

Country of origin:	West Germany
Manufacturer:	Hirth Motoren KG 7141 Benningen/Neckar Kreis Ludwigsburg
Type designation:	F-21
Rated b.h.p. @ r.p.m.:	60 bhp @ 6,000 rpm
Number of cylinders and layout:	2 cylinder in line
Combustion cycle and fuel:	2 cycle
Bore x stroke mm.:	82 x 68
Cubic capacity cc.:	718
Normal operating position:	Horizontal
Weight:	87.3 lb
Specific weight:	1.455 lb/bhp
Specific fuel consumption at rating:	Est. @ 0.9 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	54 lb
Total engine+fuel weight for 1 hour:	141.3 lb
Specific weight for 1 hour flight:	2.35 lb/bhp
Total engine+fuel weight for 2 hours:	195.3 lb
Specific weight for 2 hour flight:	3.25 lb/bhp
Estimated engine life:	
Original engine use and users:	Light aircraft
Comments:	No information from Hirth Motoren KG.

RPV ENGINE SEARCH (AGARD) HP GROUP 59

Country of origin:	Canada
Manufacturer:	Kohler of Canada Ltd. 6390 Northwest Drive Mississauga, Ontario
Type designation:	K340-2RS
Rated b.h.p. @ r.p.m.:	60 @ 8,500 would be typical
Number of cylinders and layout:	2 cylinders in line
Combustion cycle and fuel:	2 cycle Premium pump
Bore x stroke mm.:	60 x 60
Cubic capacity cc.:	339
Normal operating position:	Horizontal or vertical
Weight:	64 lb
Specific weight:	1.08 lb/bhp
Specific fuel consumption at rating:	Estimated at 1.0 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	59 lbs
Total engine fuel weight for 1 hour:	123 lbs
Specific weight for 1 hour flight:	2.08 lb/bhp
Total engine fuel weight for 2 hours:	182 lb
Specific weight for 2 hour flight:	3.08 lb/bhp
Estimated engine life:	Manufacturers confident of meeting requirement
Original engine use and users:	Racing snowmobiles
Comments:	Small bore version of the K 440-2RS. Probably the most suitable engine available in its' power range. Weight includes 150 watt alternator.

RPV ENGINE SEARCH (AGARD) HP GROUP 55

Country of origin:	France/UK
Manufacturer:	Ardem/Rollason Shoreham, England
Type designation:	4 CO2 MK X1
Rated b.h.p. @ r.p.m.:	55 bhp @ 3,300 rpm
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	4 cycle
Bore x stroke mm.:	85.5 x 69
Cubic capacity cc.:	1600
Normal operating position:	
Weight:	158 lb
Specific weight:	2.87 lb/bhp
Specific fuel consumption at rating:	0.52 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	28.6 lb
Total engine+fuel weight for 1 hour:	186.6 lb
Specific weight for 1 hour flight:	3.39 lb/bhp
Total engine+fuel weight for 2 hours:	215 lb
Specific weight for 2 hour flight:	3.91 lb/bhp
Estimated engine life:	
Original engine use and users:	Many light aircraft in Europe
Comments:	Aero-development of Volkswagen engine

RPV ENGINE SEARCH (AGARD) HP GROUP 48

Country of origin:	USA
Manufacturer:	Nelson Aircraft Corp. PO Box 454, Irwin PA 15642
Type designation:	H 63CP
Rated b.h.p. @ r.p.m.:	48 bhp @ 4,400 rpm
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	2 cycle avgas & oil
Bore x stroke mm.:	68.3 x 70
Cubic capacity cc.:	1032
Normal operating position:	Horizontal
Weight:	68 lb
Specific weight:	1.42 lb/bhp
Specific fuel consumption at rating:	Estimated at 0.9 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	43.2 lb
Total engine+fuel weight for 1 hour:	111.2 lb
Specific weight for 1 hour flight:	2.32 lb/bhp
Total engine+fuel weight for 2 hours:	154.4 lb
Specific weight for 2 hour flight:	3.22 lb/bhp
Estimated engine life:	
Original engine use and users:	
Comments:	Information from "Janes" No direct contact with manufacturer.

RPV ENGINE SEARCH (AGARD) | HP GROUP 46

Country of origin:	West Germany
Manufacturer:	Volkswagen AG Wolfsburg
Type designation:	126A - Industrial engine
Rated b.h.p. @ r.p.m.:	46 bhp @ 3,600 rpm
Number of cylinders and layout:	4 cylinder opposed
Combustion cycle and fuel:	4 cycle pump fuel
Bore x stroke mm.:	85.6 x 69
Cubic capacity cc.:	1584
Normal operating position:	Horizontal
Weight:	220 lb in auto (say 160 in aero)
Specific weight:	4.78/3.47 lb/bhp
Specific fuel consumption at rating:	0.56 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	25.8 lb
Total engine+fuel weight for 1 hour:	185.8 lb
Specific weight for 1 hour flight:	4.04 lb/bhp
Total engine+fuel weight for 2 hours:	211.6 lb
Specific weight for 2 hour flight:	4.6 lb/bhp

Estimated engine life:

Original engine use and users:

Comments: See also Ardem/Rolloson for ero development of Volkswagen engine

RPV ENGINE SEARCH (AGARD) HP GROUP 42

Country of origin:	Canada
Manufacturer:	Kohler of Canada Ltd 6390 Northwest Drive Mississauga, Ontario
Type designation:	K 440 - 2AS
Rated b.h.p. @ r.p.m.:	42 @ 7,500
Number of cylinders and layout:	2 cylinder in line
Combustion cycle and fuel:	2 cycle Premium pump
Bore x stroke mm.:	68 x 60
Cubic capacity cc.:	436
Normal operating position:	Horizontal or vertical
Weight:	64 lb
Specific weight:	1.52 lb/bhp
Specific fuel consumption at rating:	Estimate at 0.9 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	37.8 lb
Total engine+fuel weight for 1 hour:	101.8 lb
Specific weight for 1 hour flight:	2.42 lb/bhp
Total engine+fuel weight for 2 hours:	139.6 lb
Specific weight for 2 hour flight:	3.32 lb/bhp
Estimated engine life:	Manufacturers confident of meeting requirement plus.
Original engine use and users:	Snowmobiles. Many in Canada, USA and Scandanavia
Comments:	One of a range of what is probably the most highly developed 2 cycle engine in production as a bare engine. Weight includes 150 watt alternator

RPV ENGINE SEARCH (AGARD) HP GROUP 40

Country of origin:	USA
Manufacturer:	Scorpion Inc. Crosby, Minnesotta
Type designation:	Cuyuna
Rated b.h.p. @ r.p.m.:	40 bhp @ 6,500 rpm
Number of cylinders and layout:	2 cylinders in line
Combustion cycle and fuel:	2 cycle Pump fuel & oil
Bore x stroke mm.:	67.5 x 60
Cubic capacity cc.:	428
Normal operating position:	Horizontal - vertical accept'e
Weight:	62 lb
Specific weight:	1.55 lb/bhp
Specific fuel consumption at rating:	Estimated at 0.9 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	36 lb
Total engine+fuel weight for 1 hour:	98 lb
Specific weight for 1 hour flight:	2.45 lb/bhp
Total engine+fuel weight for 2 hours:	134 lb
Specific weight for 2 hour flight:	3.35 lb/bhp
Estimated engine life:	Adequate in snowmobiles
Original engine use and users:	Snowmobiles
Comments:	Highest rating of a family of engines.

RPV ENGINE SEARCH (AGARD) HP GROUP 34

Country of origin:	Canada
Manufacturer:	Kohler of Canada Ltd 6390 Northwest Drive Mississauga, Ontario
Type designation:	SK-340-2AS
Rated b.h.p. @ r.p.m.:	34 bhp @ 7,500
Number of cylinders and layout:	2 cylinder in line
Combustion cycle and fuel:	2 cycle Premium pump
Bore x stroke mm.:	60 x 60
Cubic capacity cc.:	339
Normal operating position:	Horizontal, vertical accpt'le
Weight:	64 lb
Specific weight:	1.88 lb/bhp
Specific fuel consumption at rating:	Estimated at 0.9 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	30.6 lb
Total engine+fuel weight for 1 hour:	94.6 lb
Specific weight for 1 hour flight:	2.78 lb/bhp
Total engine+fuel weight for 2 hours:	125.2 lb
Specific weight for 2 hour flight:	3.68 lb/bhp
Estimated engine life:	Manufacturers confident of meeting requirements plus.
Original engine use and users:	Snowmobile. Many in USA Canada and Scandanavia.
Comments:	One of a range of what is probably the most highly developed 2 cycle engine in production as a bare engine. Weight includes 150 watt alternator

RPV ENGINE SEARCH (AGARD) HP GROUP 32

Country of origin:	France
Manufacturer:	Automobile Citroen SA 117/167 Quai Andre Citroen 75747 Paris
Type designation:	M28
Rated b.h.p. @ r.p.m.:	32 bhp @ 5750 rpm
Number of cylinders and layout:	2 cylinders opposed
Combustion cycle and fuel:	4 cycle, pump fuel 94 RON
Bore x stroke mm.:	74 x 70
Cubic capacity cc.:	602
Normal operating position:	Horizontal
Weight:	149 lb in auto (est. 100 lb in aero)
Specific weight:	3.125 lb/bhp
Specific fuel consumption at rating:	.59 lb /bhp/hr
Estimated fuel weight for 1 hour, at rated power:	18.8 lb
Total engine+fuel weight for 1 hour:	118.8lb
Specific weight for 1 hour flight:	3.7 lb/bhp
Total engine+fuel weight for 2 hours:	137.6 lb
Specific weight for 2 hour flight:	4.3 lb/bhp
Estimated engine life:	
Original engine use and users:	Citroen Ami 6 car
Comments:	Good reliability in motor car

RPV ENGINE SEARCH (AGARD) HP GROUP 23

Country of origin:	West Germany
Manufacturer:	Fichtel & Sachs AG 8720 Schweinfurt
Type designation:	Sachs SA 340
Rated b.h.p. @ r.p.m.:	23 bhp @ 5250
Number of cylinders and layout:	Single
Combustion cycle and fuel:	2 cycle
Bore x stroke mm.:	75.5 x 75.0
Cubic capacity cc.:	336
Normal operating position:	Horizontal or vertical
Weight:	61 lb
Specific weight:	2.65 lb/bhp
Specific fuel consumption at rating:	0.75 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	17.25 lb
Total engine+fuel weight for 1 hour:	78.25 lb
Specific weight for 1 hour flight:	3.40 lb/bhp
Total engine+fuel weight for 2 hours:	95.5 lb
Specific weight for 2 hour flight:	4.15 lb/bhp
Estimated engine life:	
Original engine use and users:	Snowmobiles
Comments:	No reports on useage of this engine available.

RPV ENGINE SEARCH (AGARD) HP GROUP 22

Country of origin:	West Germany
Manufacturer:	Lloyd Motoren Werke D 28 Bremen 1
Type designation:	Lloyd LS400
Rated b.h.p. @ r.p.m.:	22 @ 5,000
Number of cylinders and layout:	2 cylinder in line
Combustion cycle and fuel:	2 cycle pump fuel and oil
Bore x stroke mm.:	62 x 64
Cubic capacity cc.:	386
Normal operating position:	Horizontal - vertical
Weight:	48 lb
Specific weight:	2.18 lb/bhp
Specific fuel consumption at rating:	.79 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	17.4 lb
Total engine+fuel weight for 1 hour:	65.38 lb
Specific weight for 1 hour flight:	2.97 lb/ bhp
Total engine+fuel weight for 2 hours:	82.8 lb
Specific weight for 2 hour flight:	3.76 lb/bhp
Estimated engine life:	
Original engine use and users:	Snowmobiles
Comments:	No reports on useage of this engine have been obtained.

RPV ENGINE SEARCH (AGARD) HP GROUP 20

Country of origin:	USA
Manufacturer:	Kolbo Korp 9902 W Broadway Anaheim CA 92804
Type designation:	D 2118
Rated b.h.p. @ r.p.m.:	20 bhp @
Number of cylinders and layout:	2 cylinder opposed
Combustion cycle and fuel:	2 cycle glo-fuel
Bore x stroke mm.:	55.54 x 39.7
Cubic capacity cc.:	193
Normal operating position:	Universal
Weight:	10.5 lb
Specific weight:	0.525 lb/bhp
Specific fuel consumption at rating:	1.8 lb/bhp-hr to 2.3
Estimated fuel weight for 1 hour, at rated power:	36 lb
Total engine+fuel weight for 1 hour:	46.5 lb
Specific weight for 1 hour flight:	2.325 lb/bhp/hr
Total engine+fuel weight for 2 hours:	82.5
Specific weight for 2 hour flight:	4.125 lb/bhp
Estimated engine life:	100 hours
Original engine use and users:	RPV
Comments:	This latest engine in Kolbo line is not yet in production

Country of origin:	USA
Manufacturer:	D H Enterprises 4909 W Compton Blvd Lawndale CA 90260
Type designation:	
Rated b.h.p. @ r.p.m.:	18 bhp @ 6,500 rpm
Number of cylinders and layout:	2 cylinder opposed
Combustion cycle and fuel:	2 cycle petrol and oil
Bore x stroke mm.:	66 x 40
Cubic capacity cc.:	273
Normal operating position:	Universal
Weight:	12.5 lb
Specific weight:	0.69 lb/bhp
Specific fuel consumption at rating:	
Estimated fuel weight for 1 hour, at rated power:	
Total engine+fuel weight for 1 hour:	
Specific weight for 1 hour flight:	
Total engine+fuel weight for 2 hours:	
Specific weight for 2 hour flight:	
Estimated engine life:	
Original engine use and users:	RPV
Comments:	It is doubtful if this can be classified as a production engine. Engine based on Stihl 090 chain saw single cylinder unit

RPV ENGINE SEARCH (AGARD) HP GROUP 15

Country of origin:	USA
Manufacturer:	Kolbo Korp. 9902 W Broadway Anaheim CA 92804
Type designation:	D 2100
Rated b.h.p. @ r.p.m.:	15 bhp @
Number of cylinders and layout:	2 cylinder opposed
Combustion cycle and fuel:	2 cycles Glofuel
Bore x stroke mm.:	
Cubic capacity cc.:	
Normal operating position:	Universal
Weight:	9.5 lb
Specific weight:	0.63 lb/bhp
Specific fuel consumption at rating:	
Estimated fuel weight for 1 hour, at rated power:	
Total engine+fuel weight for 1 hour:	
Specific weight for 1 hour flight:	
Total engine+fuel weight for 2 hours:	
Specific weight for 2 hour flight:	
Estimated engine life:	
Original engine use and users:	RPV
Comments:	

RPV ENGINE SEARCH (AGARD) HP GROUP 14

Country of origin:	USA
Manufacturer:	McCulloch Corp PO Box 92180 Los Angeles CA 90009
Type designation:	Mc101B
Rated b.h.p. @ r.p.m.:	14.5 bhp @ 9,000 rpm
Number of cylinders and layout:	Single
Combustion cycle and fuel:	2 cycle Pump fuel and oil
Bore x stroke mm.:	58 x 46.6
Cubic capacity cc.:	123
Normal operating position:	Universal
Weight:	12.25 lb
Specific weight:	0.84 lb/bhp
Specific fuel consumption at rating:	Estimated at 1.2 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	17.4
Total engine+fuel weight for 1 hour:	29.65 lb
Specific weight for 1 hour flight:	2.04 lb/bhp
Total engine+fuel weight for 2 hours:	45.05 lb
Specific weight for 2 hour flight:	3.24 lb/bhp
Estimated engine life:	Good
Original engine use and users:	One of a range of engines used in chain saws, G Kart racing etc.
Comments:	Reports of good reliability of this unit have been received from Lockheed, Shorts and indirectly from Airesearch and Teledyne - Ryan., all in RPVs However, it has been announced that this engine is no longer available.

RPV ENGINE SEARCH (AGARD) HP GROUP 12

Country of origin:	USA
Manufacturer:	Kolbo Korp. 9902 W Broadway Anaheim CA 92804
Type designation:	D 274
Rated b.h.p. @ r.p.m.:	12 @
Number of cylinders and layout:	2 cylinders opposed
Combustion cycle and fuel:	2 cycle Glofuel
Bore x stroke mm.:	46 x 36
Cubic capacity cc.:	121
Normal operating position:	Universal
Weight:	6.5 lb (with gear approx. 8.5 lb)
Specific weight:	0.54 lb/bhp
Specific fuel consumption at rating:	1.9 lb/bhp-hr
Estimated fuel weight for 1 hour, at rated power:	22.8 lb
Total engine+fuel weight for 1 hour:	29.3 lb
Specific weight for 1 hour flight:	2.44 lb/bhp
Total engine+fuel weight for 2 hours:	52.1 lb
Specific weight for 2 hour flight:	4.34 lb/bhp

Estimated engine life:

Original engine use and users:

Comments:

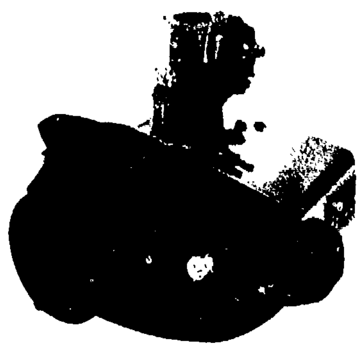
APPENDIX 3

TWO EXAMPLES OF ENGINE MODEL SPECIFICATIONS

1. McCulloch MC101D (12 hp)

MC101D 12 H.P.

The MC101D rates among the highest in the industry in horsepower to weight ratio. Mounting is easy and adaptable — in any position. Like the MC's 49, 91, and 101, the MC101D is stressed to eliminate possibility of defects and to optimize power and wear resistance. The MC101D delivers power plus.



McCULLOCH MC 101D SPECIFICATIONS:

DISPLACEMENT	7.5 cu. in. (123cc)
BORE	2.280" (58mm)
STROKE	1.835" (46.6mm)
COMPRESSION RATIO	9.4:1
WEIGHT	[illegible]
INLET VALVE	[illegible] high flow reeds on vee block for full power at all speeds and sensitivity towards inlet and exhaust tuning
CARBURETOR	The famous BDC 22 1$\frac{3}{8}$" (35mm) bore with 1$\frac{1}{8}$" (29mm) venturi assures high flow air delivery. Adjustable high and low mixture needles. Standard equipped with choke for air filter installations. Multiple throttle cable connections. Special chrome throttle shaft. Steel bushings and dirt seals to protect carburetor against dirt
AIR FILTER	Conventional types adaptable
PISTON	Heat resistant aluminum alloy. Oversize available 010" 020" 030" 050"
PISTON RINGS	Two narrow tool steel type with wear face for quick sealing, low friction and long life. Super abrasive resistant. Pinned
BEARINGS — CONN ROD	Full complement M 50 tool steel needle rollers, hardened shaft and rod ends
WRIST PIN	Two needle roller bearings in piston. Extra length for additional lubrication and cooling
MAIN	Two caged ball bearings
CRANKSHAFT	[illegible] equipped with SAE J609 $\frac{3}{4}$" diameter P.T.O. shaft. Counter balanced. Hot forged steel hardened and ground. Extensively shot peened and tungsten counterweights. Super finished throw
ENGINE	Single [illegible] two cycle air-cooled. Loop scavenged
CYLINDER CRANKCASE	Die cast aluminum alloy with precision honed cast iron [illegible] liner. Deep finned detachable head
DIRECTION OF ROTATION	Clockwise (facing power take off shaft)
IGNITION	Waterproof high tension extra high output magneto. Heat resistant moistureproof coil bonded to lamination
SPARK PLUG	Champion L 88
FUEL OIL MIXTURE	40:1 with McCulloch oil and automotive regular grade gasoline
FLYWHEEL	High pressure die cast aluminum alloy with integral magneto magnets, steel hub
STARTER	McCulloch six position automatic rewind starter is standard
COMPRESSION RELEASE	None
KILL SWITCH WIRE	Standard
CLUTCH	Conventional types adaptable
MOUNTING	Four bolt holes provided on the P.T.O. side and four [illegible] on the bottom of [illegible]. Engine operates in any position

PERFORMANCE CURVE:

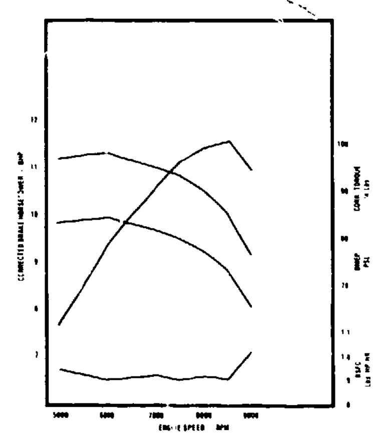
PANEL METERED FUEL-GASOLINE. STATIC TIMING 22°BTC. CARBURETOR BDC 22. EXHAUST. 90° ELBOW P/N 66131. AVERAGE OF S/N 14836, 14905, 14423 (16400170D).

POWER CURVES SHOW MAXIMUM DYNAMOMETER HORSEPOWER of engine, complete with cooling fan and exhaust header and corrected to standard sea level barometer reading of 29.62 inches and temperature of 60° F.

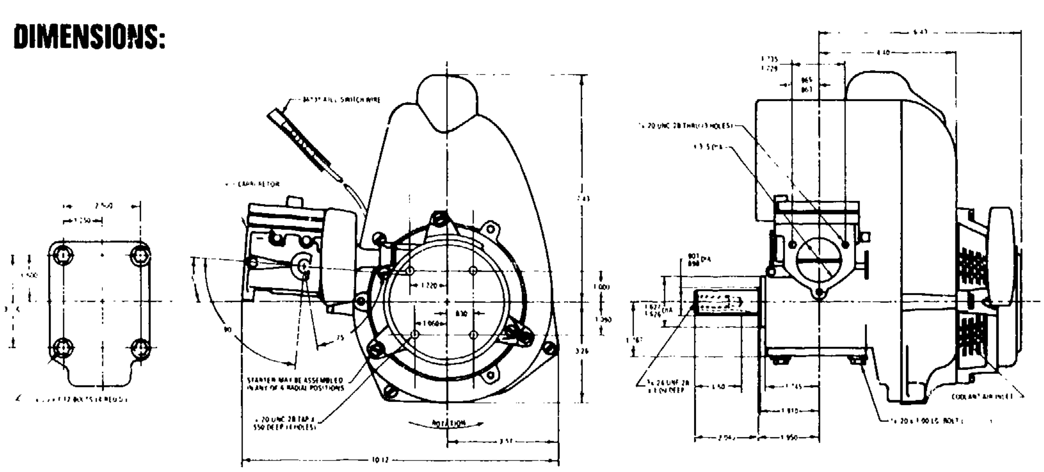
Production engines as shipped will develop at least 85% of power shown, and when run-in to reduce friction to minimum will develop at least 95% of curves.

Power will decrease 3½% for each 1000 feet of altitude above sea level and 1% for each 10° F above standard temperature of 60° F.

For CONTINUOUS OPERATION, allow 20% from power as shown as safety factor.



DIMENSIONS:



7. Rolls-Royce Continental
0-200-A
Specifications
T.S.D. Publication 4164 x)
Rolls Royce Motors Limited 1975

Engine Model Specification

A. Scope

1. This specification is for the Rolls-Royce Continental 0-200-A naturally aspirated, overhead valve, air-cooled, horizontally-opposed, direct drive, wet sump aircraft engine and includes the following data:

   Accessory Specifications
   Performance Curves

2. The 0-200-A engine described herein must be installed in accordance with the operating limitations and conditions of this specification. However, Rolls-Royce Motors Limited accept no liability whatsoever for the airworthiness of any aircraft in which these engines are installed.

3. C.A.A. Type Certificate Data Sheet Number 125.
   F.A.A. Type Certificate Number TC E 31N

B. Ratings

1. Maximum continuous brake horse power	100 bhp at 2750 r.p.m.
(a) Manifold pressure at sea level	full throttle. See graph on page A3-6
(b) Manifold pressure at critical altitude	N/A
2. Take-off Power	
(a) Manifold pressure at sea level	See graph on page A3-6
3. Maximum recommended cruise power	75 bhp at 2500 r.p.m.

C. Cylinder data

1. Number of cylinders	4	
2. Bore	4.062 in.	
3. Stroke	3.875 in.	
4. Displacement	200 cu.in.	
5. Compression ratio	7.0 : 1	
6. Firing order	1 - 3 - 2 - 4	
7. Cylinder temperatures		
(a) Head - lower spark plug thermocouple maximum allowable	525°F	274°C
recommended for cruise flight (see note J17)	420°F	200/225°C
(b) Barrel - fillet thermocouple required to be fitted on all cylinders for prototype installations. Maximum allowable temperature	290°F	143°C
8. Maximum exhaust back pressure 1.5 in. below exhaust flange	2.0 in.Hg.	

D. Propeller drive data

1. Type	AS 127 B Type 1
2. Direction of rotation (viewed from accessory end of engine looking toward propeller)	Clockwise
3. Propeller drive ratio	Direct Drive
4. Vibration dampers, number and order	None
5. Governor oil provisions	None

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E. Fuel system

1. Type	Carburettor	
2. Make and Model	Marvel Schebler MA-3SPA	
3. Fuel - Aviation Gasoline	80/87 (minimum)	
4. Fuel Filter requirements		
(a) screen mesh	100 per in.	
(b) filtration	0.005 in. max.	0.127 mm
5. Fuel Pressure at entry to carburettor	Max. 6 lbs/in.^{2}	0.4218 kg/sq.cm.
	Min. 0.3 lb/in^2	0.021 kg/sq.cm.
6. Fuel Consumption - sea level full rich (∓ 4%)	See graph on page A3-6	

F. Lubrication

1. Oil Specification (See note J9)	Mineral or MHS 24 D.Eng.RD2450 Mil-L-22851	
2. Oil Grade		
(a) above 40°F (4.4°C) ambient air at sea level	SAE 40	
(b) below 40°F (4.4°C) ambient air at sea level	SAE 20 or 10W 30	
3. Maximum Sump Capacity	5 Imp qts. 6 US qts.	5.7 Litres
(a) usable oil up to 10° nose down and 10° nose up	3.4 Imp. qts. 4 US qts.	3.8 Litres
4. Oil Filter - full flow	Not supplied by Rolls-Royce Motors	
5. Oil Cooler	Customer option (see Parts Manual for details)	
6. Oil Pressure		
(a) normal operation	30 - 60 lb/sq.in. 2.1 - 4.2 kg/sq.cm.	
(b) minimum idle (hot)	10 lb/sq.in. 0.7 kg/sq.cm.	
(c) maximum allowable (cold)	100 lb/sq.in. 7.0 kg/sq.cm.	
7. Oil Temperature		
(a) maximum allowable (see Note J9)	225°F	107°C
(b) recomended take-off minimum	75°F	24°C
(c) recommended for cruise flight (see note J17)	170°F	75/85°C
8. Oil Consumption		
(a) up to 75% power	0.010 lb/bhp/hr	
(b) above 75% power	0.010 lb/bhp/hr	
9. Heat rejection to oil cooler at rated power and r.p.m.	300 BThU/Min	
10. Oil Flow	30 lbs/min	

G. Ignition system

1. Magnetos, harness, spark plugs	See Accessory Specifications	
2. Timing		
(a) right magneto	28° BTDC	
(b) left magneto	28° BTDC	
3. Magneto temperature (coil attachment) maximum	170°F	77°C

H. Accessory data

See page A3-5

1. Alternator Temperature - maximum	Diode 275°F	135°C
	Winding 300°F	149°C

J. Installation data and notes

1. Propeller Mount
   The propellor attaching bolts are not supplied with the engine.

2. Centre of Gravity location
   The location of the centre of gravity is shown on the installation drawing (not included).

3. Engine Mounting
   The engine is provided with four rear-mounted ring type mounting brackets to which vibration isolation assemblies can be attached. The aircraft mounting frame must be fully stabilised.

4. A thermocouple located adjacent to any engine part, excluding cylinder assemblies, shall not exceed 250°F (121 C).

5. Fuel Metering System

(a) Carburettor	See section E/2
(b) Fuel inlet connection for fuel pump	0.437-20 NF tapped connection

6. Air Intake Scoop and Filter
   An air scoop and filter assembly is supplied with the engine. The air scoop is fitted with an entry point for heated air and a lever operated hot air selection flap for the carburettor.

7. Vacuum Pump
   (a) a fully machined vacuum pump pad is provided, blanked off with a cover plate.
   (b) the vacuum pump oil return tapping is provided in the accessory case on the 2-4 side near to the lower engine mounting boss - size 0.375 - 18 NPTF.

8. Oil Sump
   The engine is equipped with a sheet metal oil sump.
   (a) an oil gauge rod, which indicates full at 5 Imp qts. (6 US qts. 5.7 Litres), is integral with the oil filler cap and has graduated oil levels.
   (b) the oil drain plug at the bottom of the sump has a 0.625 - 18 NF-3 thread.
   (c) the oil filler neck is located on the 1-3 side of the oil sump.

9. On engines where the option of MHS-24 oil is selected, straight mineral oil is required for the first 20 to 30 hours to promote faster ring seating and oil control. A maximum oil temperature of 240°F (115°C) is permissible when using MHS-[illegible] oil or when using straight mineral oil during the first change period. Oil cap assembly 633[illegible].1 must be used when the maximum temperature limit is specified at 240°F.

10. Oil Temperature Measurement
    A tapped connection is provided in the crankcase adapter block on the 1-3 side of the engine for a temperature sensing probe.
    Thread size 0.625-18UNF-3B

11. Oil Pressure Connection
    A tapped threaded connection is provided in the 1-3 side of the crankcase between no. 1 cylinder and the accessory drive casing.
    0.125-27 NPTF

12. Crankcase Breather
    A fitting for a hose connection is provided at the propeller end of the engine on the 1-3 side.
    0.625 in. diameter

13. Valve Gear
    The overhead valves are operated by push rods and hydraulic tappets.

14. Intake Manifold Pressure Connection
    A tapped threaded connection is provided in the intake manifold for measuring manifold pressure.

15. Inter-Cylinder Baffles
    Not supplied.

16. Exhaust Manifolds
    A set of gaskets and brass nuts for securing the exhaust manifold is provided with the engine.

17. The "recommended" oil and cylinder temperature are for guidance during level cruise flight at 75% power in the ambient for which the aircraft is certificated.

K. Engine shipping

1. Preparation for delivery
   Each engine is packaged, marked and preserved for a period of 180 days.

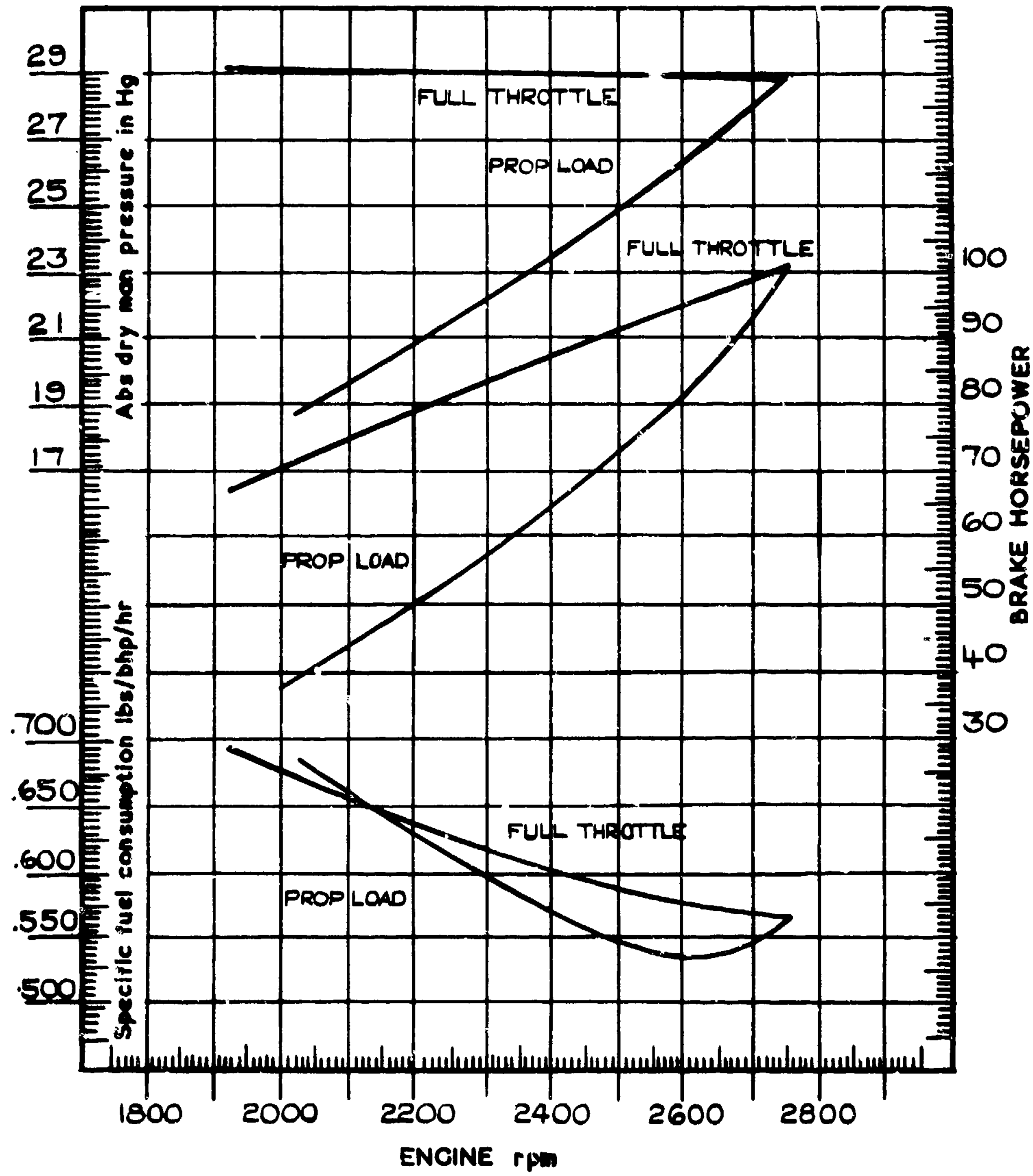
ENGINE ACCESSORY SPECIFICATION

Description	Weight	
x Magnetos Scintilla S4LN-21	11.5 lbs	5.1 kg
Ignition Harness Assy. 7 mm	3.8 lbs	1.7 kg
OR		
x Magnetos & Ignition Harness Assy. Slick Electro 4001	11.60 lbs	5.2 kg
x 8 off 18 mm Spark Plugs	1.75 lbs	0.7 kg
Oil Cooler (Harrison EQ 5334)	4.25 lbs	1.9 kg
x Mechanical Tachometer (AS54)	.12 lbs	.05 kg
Generator 12v 35A	9.80 lbs	4.4 kg
Alternator 12v 60A	11.8 lbs	5.2 kg
Voltage regulator	1.75 lbs	0.7 kg
Starter Motor 12v (Delco Remy)	15.50 lbs	6.9 kg
Starter Motor 12v (Prestolite)	15.25 lbs	6.8 kg
Basic Engine weight of engine not including accessories	170.2 lbs	75.6 kg
Weight including necessary (x) accessories	187.9 lbs	83.5 kg
Total engine dry weight including typically fitted accessories	220 lbs	97.8 kg

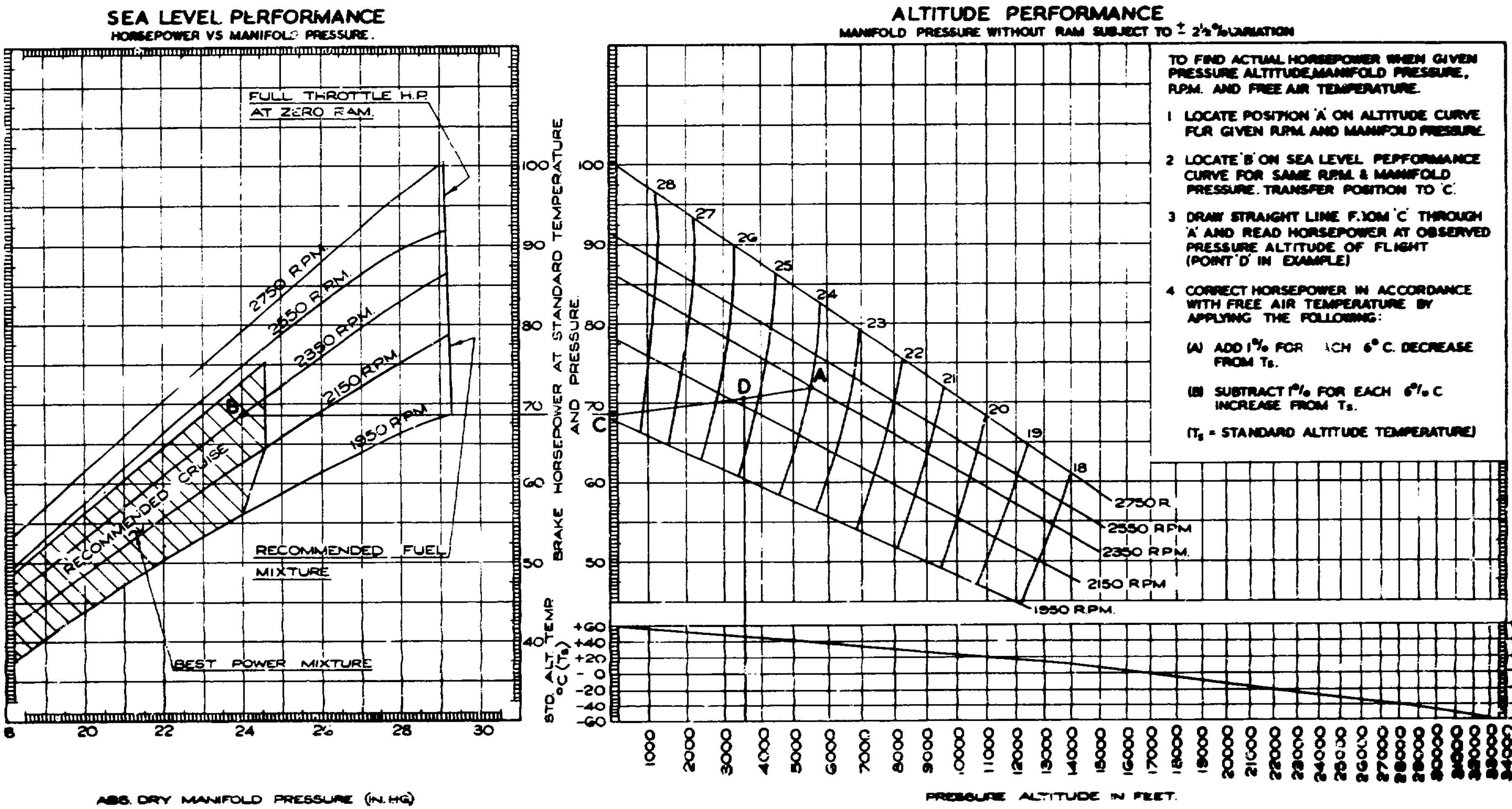
ACCESSORY DATA

Drive Accessory	Directio of Rotation	Drive Ratio to Crankshaft	Maximum Torque Continuous lb.in	Maximum Torque Continuous kg.cm	Maximum Torque Static lb.in	Maximum Torque Static kg.cm	Maximum overhand Moment lb.in	Maximum overhand Moment kg.cm
x tachometer	clockwise	0.500 : 1	7	8	50	58	25	29
x magnetos	clockwise	1.000 : 1						
x starter motor	clockwise							
x alternator	anti-clockwise	2.035 : 1	30	35	100	115	100	115
x vacuum pump	anti-clockwise	1.000 : 1	40	46	800	920		

x direction of rotation looking into the drive on engine.



Rolls Royce Continental 0-200-A
Sea level performance curves



Engine model 0-200-A

APPENDIX 4

SPECIFICATION OF RECIPROCATING ENGINE FOR SMALL REMOTELY PILOTED VEHICLE

1. SCOPE

1.1 This specification covers the requirements for the development and testing of an air-cooled, reciprocating, spark ignition type engine for use in mini-RPV's.

2. APPLICABLE DOCUMENTS

2.1 The following specifications, in effect on date of invitation for bids, form a part of this specification:

SPECIFICATIONS

Military

MIL-STD-461A - Electromagnetic Interference Characteristics Requirements for Equipment

TTP-1757 - Primer, Zinc-Chromate, For Aircraft Use

TTE-489 - Enamel, Gloss, For Aircraft Use

3. REQUIREMENTS

3.1 Qualification - The engine furnished under this specification shall be a product which has been tested and has passed the tests specified herein.

3.2 Materials and Parts

3.2.1. Materials - Materials used in the manufacture of this engine shall be of a quality suitable for the purpose and shall conform to good commercial practices. Particular attention shall be paid to the selection of materials which are not classified as critical (i.e., nickel based superalloys).

3.2.2. Parts - Standard parts (AN or MS part numbers) shall be used to the maximum extent practicable. The use of nonstandard parts shall be subject to the approval of the Government. (Standard parts shall include nuts, bolts, washers, "O" rings, etc.)

3.2.3. Dissimilar Metals - Contacts between dissimilar metals shall be avoided wherever possible. Where such contacts are unavoidable, they shall be insulated in the best practical manner in accordance with the design characteristics of the engine.

3.3 Drawings - Drawings and their applicability shall be defined by the using Service.

3.4 Aircraft Structural Load and Maneuver Rate Requirements

3.4.1. Structural Load Requirement - The structural load design shall conform to the following:

Normal Acceleration	$\pm$ 6g's
Axial Acceleration	$\pm$ 10g's
Lateral Acceleration	$\pm$ 3g's

3.4.2. Maneuver Rate Requirement - The maneuvering rate design shall conform to the following:

Yaw	12°/sec
Pitch	30°/sec
Roll	60°/sec

3.5 Performance Requirements - Engine performance shall be as follows:

3.5.1. Engine Ratings - When supplied with a reference fuel conforming to standard commercial grades and oil conforming to currently available commercial standards, the engine shall have the following performance ratings:

Power	Nominally ___BHP (___KW) at 29.0 in Hg (dry), 85°F (excludes muffler and alternator) and __________rpm output shaft speed
Specific fuel consumption at sea level, wide open throttle	___ lb/BHP/hr (____KG/KW-hr)
Maximum cylinder head temperature at spark plug	500°F (260°C)

3.5.2. Exhaust Noise Attenuation - The engine design shall consider the adaptation of an exhaust noise attenuating device. The muffler noise level reduction is expected to be 3db below each of the band width levels shown in the table below. Numbers quoted are for 300 feet slant range at 200 feet altitude on 60°F day with 7% relative humidity, no wind and 60-70 knot vehicle flight speed. Measured data is to be corrected to fit these conditions.

Octave Band Center Frequency, Hz

16	31.5	63	125	250	500	1000	2000	4000	8000
91	68	55	55	45	35	37	39	40	50

Maximum level in any one singular octave band assuming no contribution from an adjacent band. The power penalty for typical values of exhaust back-pressure shall be measured according to the test procedure of paragraph 4.1.

3.5.3. Growth Capability - The basic engine shall be capable of uprating/derating ± 25% in maximum power output with no major redesign required. Method of growth shall be defined; i.e., rpm increase, carburetor changes, stroke change by shimming.

3.5.4. Design Life - The engine shall have a design life of ____ hours at the ___ HP nominal rating. Life at the uprated condition shall be defined by contractor.

3.5.5. General Characteristics - The engine shall have low vibration, be capable of rapid and smooth acceleration/deceleration, and produce no visible smoke.

3.6 Operational Requirements

3.6.1. Cylinder Head Temperatures - The maximum allowable cylinder head temperature measured at the spark plug shall not exceed 500°F (260°C) after two minutes of static operation with a propeller at maximum power with full rich fuel-air mixture.

3.6.2. Altitude Capability - The engine shall be satisfactory for operation without misfiring or stalling up to and including _____ feet (____m) density altitude.

3.6.3. IR Radiation Reduction - The engine design shall be configured to integrate IR radiation reduction in terms of self cooling or minimum exposure of hot parts (i.e., baffles, shrouding).

3.7 Physical Requirements

3.7.1. Overall Dimensions - The overall dimensions of the engine shall not exceed the following:

Length	To be supplied by manufacturer
Width	To be supplied by manufacturer
Height	To be supplied by manufacturer

3.7.2. Engine Mounting - The engine shall be designed for cantilever firewall mounting.

3.7.3. Weight - The dry weight of the complete engine shall not exceed ___ lb/BHP (___ KG/KW). The complete engine consists of the following components: Basic engine, carburetor, ignition system, propeller hub, and engine instrumentation.

3.7.4. Propeller - The engine shall have a propeller shaft with a single flanged hub suitable for installation of a fixed or controllable pitch propeller. The direction of rotation shall be clockwise when viewed from the anti-propeller end. The propeller shall have a direct or geared drive as specified by the contractor.

3.7.5. Engine Instrumentation - The engine shall be capable of accepting, without modification, a spark plug gasket type thermocouple and have an integral mount for a Government approved engine speed transducer.

3.7.6. Fuel Metering System - The engine shall be equipped with a diaphragm type carburetor having a suction fuel capability of 24 inches (61cm) H_2O and capable of operating in all vehicle maneuvering attitudes.

3.7.6.1. Fuel Screen - A readily accessible fuel screen or filter shall be provided in the carburetor at the point of fuel entry into the carburetor or in the fuel supply line adjacent to the point of fuel entry into the carburetor.

3.7.6.2. Mixture Control - The carburetor shall be equipped with the minimum number of suitable mixture control devices (readily accessible if manually operated) necessary to maintain the correct fuel-air ratio so that the engine will meet the requirements of paragraph 3.5. and 3.6.

3.7.7. Engine Starting - The engine shall be started by means of an auxiliary electric starter utilizing output shaft in a manner specified by the manufacturer.

3.7.7.1. Starting Capability - The engine shall be capable of starting from -65°F to 120°F (-54°C to 49°C) ambient temperatures. Starting aids required for low temperature shall not be made an integral part of the engine and shall be specified as to type and temperature by the manufacturer.

3.7.8. Lubricating System - To be defined by the manufacturer.

3.7.9. Ignition System - The engine shall be provided with an ignition system as specified by the manufacturer. Solid state, self contained ignition system preferred.

3.7.9.1. Radio Shielded Ignition Assembly - The engine ignition system shall be of low EMI design conforming to the requirements of MIL-STD-461A Notice 6.

3.7.9.2. Spark Plugs - The engine shall be fitted with ___ spark plug(s) in each cylinder, type to be specified by the manufacturer.

3.7.10. Accessory Pads and Drives - Provisions shall be made on the engine for direct driving an alternator of ____ watts.

3.8 Engine Data Plate - A data plate shall be attached to the engine and shall include only the following information:

a. Model

b. Manufacturer's serial number

c. Contract number

d. Acceptance Date

e. Manufacturer's name and trademark

3.9 Protective Treatment - With exception of the parts listed below, all exposed metal surfaces shall be painted with one coat of primer and one finish coat:

a. Cylinder

b. Magneto (if any)

c. Machined mating surfaces

d. Carburetor

3.9.1. Primer Coat - The primer shall be zinc chromate and shall conform to Specification TTP-1757.

3.9.2. Finish Coat - The finish coat for the basic engine shall conform to the requirements of Specification TTE-489.

3.10 Interchangeability - Insofar as practicable, all parts having the same manufacturer's part number shall be directly and completely interchangeable with each other with respect to installation and performance.

3.11 Workmanship - The workmanship and finish on all parts shall be in accordance with high grade shop practices.

4. QUALITY ASSURANCE PROVISIONS

4.1 Tests - The acceptance of this engine is predicated on the satisfactory completion of preliminary qualification tests to be conducted at the contractor's plant and acceptance tests to be conducted at the user designated test facility.

4.1.1. Preliminary Acceptance Tests - The manufacturer shall conduct a preliminary qualification test on each engine to be delivered to the Government according to the following operating cycle:

Mode	Power Level	Time in Mode
Start & Idle	Idle	1 min
Takeoff	100%	3 min
Climb	90%	10 min
Cruise	75%	60 min
Approach	Idle	2 min
Landing Abort	100%	2 min
Cruise	75%	2 min
Idle & Shutdown	Idle	2 min

This cycle shall be repeated a total of three (3) times and shall be run on a test stand with a propeller specified by the user.

4.1.1.1 Retests - Whenever the user determines there is evidence of insufficient power or other malfunctioning of the engine, the difficulty shall be investigated and its cause corrected to the satisfaction of the user before the test is continued. If such investigation requires disassembly of the basic engine, the engine shall be retested. The retest shall include portions of or the complete tests in 4.1.1. at the option of the user.

4.1.2. Acceptance Tests - Following preliminary acceptance testing at the manufacturer's plant, an evaluation lot of engines shall be delivered to the designated Government test facility for acceptance tests. These tests shall include, but not be limited to, those listed in this section.

4.1.2.1. Sea Level Performance - Performance at the sea level, standard day condition (or as nearly as possible) shall be measured according to the following:

a. Wide-Open Throttle (WOT) power and sfc through the operating rpm range

b. Variable speed and load sfc characteristics

c. Engine accel/decel characteristics

d. Exhaust backpressure performance effects

4.1.2.2. Environmental/Vulnerability Tests - Environmental performance and vulnerability measurements shall be acquired through the following tests:

a. Altitude performance, full and part-throttle, from sea level through _______ ft (________ m) density altitude

b. Low temperature starting and performance at -65°F (-54°C)

c. High temperature starting and performance at 120°F (49°C)

d. Electromagnetic Interference (EMI) Measurement

e. Infrared Radiation (IR) Measurement

4.1.2.3. Endurance - The engine shall be mounted on a test stand with a propeller selected by the user and be run over an endurance test cycle similar to that of paragraph 4.1.1. for a period of at least ___ ___ hours engine operating time.

4.1.2.4. Dives - Upon completion of the endurance run and without intervening major disassembly, the engine shall be subjected to _______(   ) simulated dives of one minute ± 3 seconds each duration at 110% normal rated speed. Dives shall be conducted at full throttle. Dives shall be alternated with stabilizing runs of about 5 minutes

duration each at 60 to 80% of normal rated speed. Acceleration and deceleration shall each be accomplished in a period not longer than 10 seconds. The time for changing speed shall not be deducted from the specified duration time for dives.

APPENDIX 5

SURVEY OF U.S. AUXILIARY POWER UNITS

A brief survey was made of small, shaft power (< 150 BHP) gas turbine engines in the U.S. At present time, it seems that no engines of this power class are being developed for aircraft type applications. However, there are a large number of small shaft power gas turbines currently being developed and produced as auxiliary power units (APU's) for large aircraft. The gas generator part of these APU's could be adapted, with appropriate gear reduction, for possible turbo-prop applications. The table on this page present data on some units, which are likely candidates for this application.
In addition to the examples given, there are many more small gas turbines, which are used to provide a combination of shaft horse power and bleed air extraction. These could also be modified to all shaft power output. The enclosed units represent, however, a reasonable cross-section of available small gas turbines.

Some data on U.S. Auxiliary Power Units

Engine manufacturer	Garret AiResearch				SOLAR
Engine type	GTP 30-67	GTP 30-67B	GTP 30-141	GTP 30-150	T62T-40-8
Power S.L. static hp	32.3	85	100	130	210
Spec. fuel consumpt. lb/hp-h	0.85	0.56	0.60	0.482	0.43
Compressor shaft speed RPM	52,870	59,200	59,200	59,200	62,000
Max. operating altitude m	3050	3050	7600	7600	10700
Inlet temp. capability K	328	328	328	328	340
Max. length mm	655	670	620	642	620
Max. width x height mm	437x513	510x510	530x590	530x445	382x457
Compressor inlet area mm^2	1160	1160	2140	1750	NA
Weight incl. gearbox x) kg	40.5	44.0	53.5	50.0	39.6
Weight power section only kg	< 20.0	< 20.0	< 25.0	< 25.0	18.8
Lubrication system type	oil mist	-	NA	NA	oil mist
Fuel control type	const. speed	const. speed	const. speed	const. speed-automatic	const. speed
Capable of receiving mainten.	yes	yes	yes	yes	yes
Fabrication methods:					
compressor	forging	forging	forging	forging	forged titan.
combustor	sheet metal	sheet metal	sheet metal	sheet metal	steel
turbine	casting.	casting	casting	casting	INCO 713 LC
housings	sheet metal	sheet metal	sheet metal	sheet metal	aluminium
Cost per unit - 500 units	NA	NA	NA	NA	ca.$25000
- 1000 units	NA	NA	NA	NA	> $15000 < $25000
Mean time between overhauls - hrs	5000	5000	5000	5000	2600
Est. life with normal mainten. - hrs	6400	6400	6400	6400	> 3000
Smoke	unknown	unknown	unknown	unknown	non-visible
g-load capability - radial	15 g	15 g	15 g	15 g	8 g
- axial	20 g	20 g	20 g	20 g	8 g
Method used for starting	electric Ni-Cad. battery	electric: 28 VDC infinite bus	electric: 24 VDC	electric: 24 VDC	electric or hydraulic
Production status:	in production	prototype	limited production	prototype	in develop-ment

x) Gear reduction to 8000 rpm.

APPENDIX 6

NOTE ON A TURBOSHAFT ENGINE IN THE POWER RANGE 30-50 hp, SUITABLE FOR HELICOPTER RPV

1. The considered use of small RPV's for reconnaissance and surveillance has led to design studies of small unmanned helicopters having power requirements in the range 20-50 hp, depending on payload and endurance requirements.
2. In general, the propulsion requirements for such small vehicles have been poorly served. While a selection of 2- and 4- stroke piston engines exists and has been reported in the Weslake survey (Appendix 2), there may be reasons for not using a piston engine in preference to a turbine engine in such RPV's. This preference may arise from considerations of vibration limitations on vehicle sensor equipment. Generally a turbine may be expected to be more acceptable from a vibration standpoint than a piston engine and if considerations of cost and SFC are not mandatory in the vehicle/mission analysis, then the good vibration characteristics of the turbine engine may dominate in the selection of propulsion system for vehicle in which certain types of sensor are carried. For this reason, the turboshaft engine described in this note is typical of the approach made by engine manufacturers to the problem of providing a propulsion system for an RPV for which no engine is available.
3. Among the Companies concerned with this problem is Lucas Aerospace. Lucas gas turbine starters and auxiliary power units are well known for aircraft use and a particular unit has been chosen as the basis of a re-design for turboshaft drive to the rotors of a helicopter RPV. The unit selected for re-design is the Lucas CT 2009 which, in various forms, has been used extensively in the Harrier VSTOL Strike aircraft. The proposed new engine was basically the gas generator part of the CT 2009 free power turbine engine, and the new designation of the proposed unit was CT 2047. This proposed engine had a power output capability of 50 SHP and was chosen as a single-shaft engine in preference to the two-shaft free turbine engine, in the interest of installation simplicity. In the installation considered, the engine was required to be mounted vertically with the rotor drive downwards and the exhaust upwards. This single-shaft engine CT 2047, derived from the free-turbine CT 2009 GTS/APU is described below.
4. The CT 2047 comprises a single-stage centrifugal compressor, with an impellor of 117 mm diameter, and a single-stage inward flow radial turbine. This unit has output of 50 SHP at 68,000 rpm, ISA at sea-level, and a combustion temperature of 1200°K. For the particular application at the time only 32 HP was required at an ambient temperature of 40°C, i.e. ISA + 25°, and this was achieved by derating the engine to operate at 1060°K combustion temperature, which is very conservative.
5. Performance, i.e. shaft horse-power and fuel-flow/combustion temperature, is shown in Fig. A6-1.
6. It is evident that the corresponding values of SFC tend to be high. This is attributable to the low efficiency of the turbine which results from the fact that it is operating at a higher expansion ratio than it was originally designed for in the original CT 2009 GST/APU. Ideally, the proper solution to achieve a high level of turbine efficiency would be to design the turbine to two stages, and in fact Lucas Aerospace has considered such a re-design.
7. The engine consists of a single-stage centrifugal compressor, an annular reverse-flow combustion chamber, a 10-blade radial inward-flow turbine, an exhaust duct, a power output gearbox and an ignition/fuel system. These engine components are briefly described below and an engine weight summary is given:
   - 7.1 The compressor consists of three major components.
     - 7.1.1. Pre-whirl vanes cast integrally with the intake casing.
     - 7.1.2. The rotor consisting of a separate steel rotating guide vane (13 blades) and an aluminium impellor (13 full blade and 13 half-blades) shrunk onto the single shaft.
     - 7.1.3. Diffuser and casings, with 15 diffuser vanes cast integrally with the compressor back plate.
   - 7.2. The combustion chamber is very compact and annular, utilizing flat spray atomizers with flow-straightener vanes out of the compressor.
   - 7.3 The turbine employs 13 nozzle vanes at entry with expansion through a 10-blade radial inward-flow rotor, and an upper entry-temperature limit of 1200°K.
   - 7.4 The gearbox could consist of a compound planetary system of spur gears, producing a reduction ratio of 34:1. At the output end the transmission could be split into parallel contra-rotating output shafts, or remain as a single shaft, depending on the choice of rotor system employed by the vehicle. Engine accessories would be mounted on the gearbox casing and would be driven through subsidiary gears off the main train.
   - 7.5 Ignition is a 2-Joule transistorized component providing 800 sparks per minute with a 28-volt input.
   - 7.6 The fuel system consists of the following:
     - 7.6.1. Gear pump and constant-speed governor
     - 7.6.2. Pressure-raising valve
     - 7.6.3. Altitude-compensation unit
     - 7.6.4. Shut-off dump valve

   Engine speed can be regulated through the governor to within 2% of nominal-speed. Starting is achieved by an external electric motor and disengagement during run-up to ground idling speed is achieved through a sprag clutch incorporated in the motor drive.
8. The weight breakdown is as follows:

8.1 Engine, combustion chamber, exhaust	10.45 kg
8.2 Gearbox	5.25 kg
8.3 Accessories (Fuel-pump/governor, soc Oil pump, alternator, wiring, pipes)	4.64 kg
Total:	20.34 kg
8.4 Auxiliaries (Starter, ignition, ECU)	4.14 kg
Gross weight	24.48 kg

   These weight are derived from weighed components of the primary GTS/APU and an estimated gearbox weight. Re-design into a more optimized turboshaft unit might reduce overall weights by 2-3 kg.
9. Reliability analyses of the GTS/APU in Harrier service indicate that the new CT 2047 should achieve an overall failure rate of less than $1000/10^6$ hours i.e. an MTBF of at least 1000 hours.

10. Development of this engine might be expected to require two years to delivery of a type-approved unit.
11. An indication of the application of this unit to vehicles defined by power/weight ratio, payload and endurance at full power is given by calculating (engine) values of propulsion specific weight:

$\frac{\text{(engine + fuel weight)}}{\text{SHP}}$ for zero, 1 and 2 hours endurance. These values are given below over the power range of the CT 2047, i.e. 32-50 SHP:

Engine SHP	32	40	45	50
Engine weight (lb)	45	45	45	45
Fuel flow (lb/hr)	62	72	78	85
$(W_{ENG} + W_{FUEL})$ 1 hour	107	117	123	130
$(W_{ENG} + W_{FUEL})$ 2 hour	169	189	201	215
SFC (lb/SHP/hr)	1.94	1.80	1.73	1.70
W_{ENG}/SHP	1.41	1.13	1.00	0.90
$\left(\frac{W_{ENG} + W_{FUEL}}{SHP}\right)$ 1 hr	3.35	2.9[illegible]	2.73	2.60
$\left(\frac{W_{ENG} + W_{FUEL}}{SHP}\right)$ 2 hr	5.29	4.73	4.46	4.30

These values of propulsion specific weight are plotted on to the parametric data of Fig. 2.4 of the main report, and show a simple comparison with currently available 2- and 4-stroke piston engines, on the basis of applicability to rotary or fixed-wing vehicles. No costs are available, so that no comparison between engines can be made on the basis of cost-effectiveness.

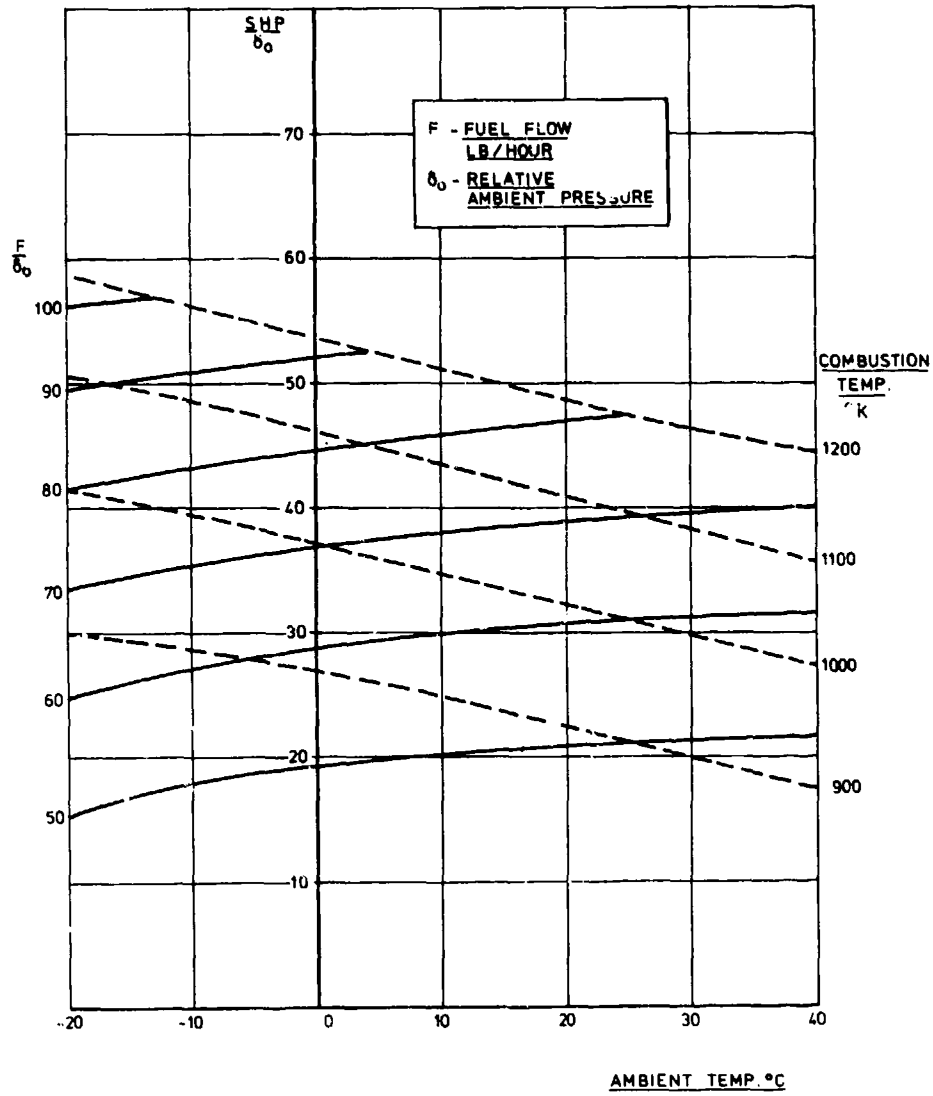


Fig.A6-1 Performance curves, Lucas CT 2047 turbo-shaft engine

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14. Abstract

In this report engines in the power range up to 100 hp are studied for application into small propeller-driven RPVs. From an inventory of existing engines, it is found that a number of two- and four-stroke piston engines in this power class are available, but most of them will not fulfill the requirements for RPV-applications with respect to reliability, quality control, noise, vibrations, etc. Up till now no other types of shaft-power engines are available for application to small RPVs, although turboshaft engines and possibly also electrically-driven propellers might offer advantages for some missions.

For payloads between 10 and 50 kg and flight endurances of up to 3 hours some parametric calculations are presented for fixed-wing and rotary-wing vehicles, to illustrate vehicle sizes and engine power requirements.

Some recommendations are given for the future development of piston- and turbo-shaft engines suitable for propeller-driven RPVs, emphasizing the need for Demonstrator Engine Programs. Data on actual and projected engines and some typical specifications are added in appendices.

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